AF INSTITUTE OF TECHNOLOGY

XPERIMENTAL INVESTIGATION OF A CHEMICA LASER CAVITY FLOWFIELD

THESIS

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AFIT/GAE/ENY/89D-36

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THESIS

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Preface

I selected my thesis topic for three reasons. The primary reason was to apply my newly acquired classroom knowledge to a practical fluids problem. Secondly, I wanted to do research in a field that could benefit current Air Force interests, and finally, to do an experimental thesis to integrate thirteen years of electronics experience with my newly acquired aeronautical fluid dynamics knowledge.

The successful completion of any project requires the hard work of many people. Of all the hard working people, Dr. W. C. Elrod, my thesis advisor, played the most important part. I am deeply grateful for his guidance and support. He was always available and many hours were spent in guiding me to a successful conclusion to my research. I'd also like to thank my committee members, Dr. M. E. Franke and Lt Col P. I. King, for the benefit of their extensive knowledge and helpful suggestions. Their support was greatly appreciated.

Someone once told me a good sponsor is one that identifies the general scope of the project, provides the necessary funds, and then leaves the researcher to do his job. If that's so, then I was truly blessed! My thanks go out to the AFWL team, especially Capt Gregory Gates, for suggesting the project, providing the necessary information, and last but not least, providing the funding to put it all together. This report is just a small piece of the big picture, but with continued support, it could also be the first piece in the solution to a bigger puzzle.

Laboratory work requires the sucessful acquisition and operation of many pieces of hardware. Mr. Nicholas Yardich and the AFIT/ENY technicians were always readily available with their knowledge and guidance. I especially thank Mr. Yardich for all the help in ordering equipment, Mark Derriso for always finding the part I needed, and Jay Anderson for knowing how to put it all together and make it run.

Experimental work requires the design and fabrication of many pieces of hardware, and the AFIT Model Shop provides the expertise necessary to accomplish the job. At one time or another, every one of the craftsmen at the model shop played a role in the fabrication of hardware for my research and the high quality of their work is greatly appreciated. I want to especially thank Jack Tiffany for knowing where to find the difficult-to-obtain parts and John Brohas for doing such an excellent job on the test section and diffuser. John Brohas's technical experience combined with his craftsman skill were significant factors in establishing and frabricating the final design in a timely manner.

Experimental work is taking theory and putting it to work. During the application of the theory, the experimentalist identifies problem areas and attempts to determine solutions to the problems. Many of the problems have been seen before but, unless an experimentalist has had past experience, he must sometime reinvent the wheel. Capt F. Tanis's suggestions and gentle guidance based on his experimental experience and computer knowledge saved me a tremendous amount of time and was greatly appreciated.

I would also like to thank my wife and three children for their tremendous patience and support throughout this entire program. I would not be where I am today if it wasn't for their encouragement.

Finally, I would like to dedicate this paper to my father and mother, Stephen W. Stiglich, Sr. and Norma R. Stiglich. Their continued belief in me has never faltered. Thanks Mom and Dad!

Stephen Walter Stiglich, Jr.

Table of Contents

List of Figures

Figure | Page

Figure Page

List of Tables

List Of Symbols

Symbol	Definition
A	area
A/D	analog–to–digital
AECP	Airman Education and Commissioning Program
AFWL	Air Force Weapons Laboratory
b	$\frac{\gamma+1}{\gamma-1}$
C	dimensionless Crocco number
CD	converging–diverging
CL	Chemical Laser
DARS	Data Acquisition and Reduction System
DEW	Directed Energy Weapons
GBL	Ground–based Laser
k	kilo
M	Mach number, Mega
NDEW	Nuclear Directed Energy Weapon
P, p	pressure
SBL	Space-based Laser
SBPB	Space-based Partical Beams
SCU	signal conditioning unit
SDI	Strategic Defense Initiative
T t	temperature
u	velocity
γ	ratio of specific heats
δ	boundary layer thickness, deflection angle
η	dimensionless coordinate

Symbol	Definition
ϑ	streamline angle
ν	Prandtl–Meyer function
ξ	$\frac{p_4}{p_3}$

Subscripts

0	stagnation value
1, 2, 3, 4	conditions at a position
a	conditions in the free stream adjacent to the dissipative regions
c	calculated
d	conditions along the discriminating streamline
e	exit conditions
i	floating index
j	conditions along the jet-boundary streamline
max	maximum
R	large co–ordinate reference value
red	reduced approach conditions
t	true

Abstract

Chemical lasers require a cavity that establishes and maintains the proper gas dynamic properties during lasing. The design and performance of a flow system capable of supporting the hypersonic flow conditions in a lasing cavity are described. Using cold air as the working medium, the flow control system configuration and nozzle-cavity-supersonic diffuser assembly configuration were developed to establish acceptable flow conditions in the test section. Performance evaluation was based on pressure measurements in the nozzle-cavity-diffuser assembly and schlieren photographs of the flowfield in the cavity.

Flow conditions in the test section were broken up into three different regions: flow in the hypersonic nozzles, flow in the base region and flow in the cavity region.

Flow in the nozzles was analyized using one–dimensional, steady, isentropic flow theory. Test results indicated that the hypersonic nozzles performed to design specifications.

The Korst two–dimensional base–pressure flow model was used to describe the flow in the nozzle exit plane and base region. Experimentally calculated Mach numbers and static pressures corresponded very closely to theoretical values.

Static pressure ports and schlieren photographs were used to describe the flowfield conditions in the cavity region. Pressure measurements indicated that supersonic conditions were reached in the cavity for specific supersonic diffuser throat areas settings, but conditions were short lived. Boundary layer, frictional, and three–dimensional effects were suspected as the main contributors to the flowfield degradation.

EXPERIMENTAL INVESTIGATION OF A CHEMICAL LASER CAVITY FLOWFIELD

I. Introduction

1.1 Background

Chemical lasers and their direct application to the Strategic Defense Initiative (SDI) have caused a large increase in chemical laser research. In fact, current concepts for the Directed Energy Weapons (DEW) program, a subprogram of SDI, have stimulated interest in four promising areas. The areas are: space–based lasers (SBL), ground–based lasers (GBL), space–based partical beams (SBPB), and nuclear directed energy weapons (NDEW). Decisions on whether or not the Chemical Laser (CL) is used in SDI is directly related to the performance of the laser.

Chemical laser performance, or more specifically the beam quality, is directly dependent on the flow structure in the lasing cavity. Laser performance is strongly connected to the fluid mechanics processes of the flow crossed by the beam. Rapagnani and Lankford from the Air Force Weapons Laboratory (AFWL) state:

> Computer modelling of the flow through cavities is not a trival task. Anaylsis of the flows are complicated by the existence of strong cross–stream pressure gradients and subsonic recirculation zones that are embedded in the supersonic cavity. This analysis of a high base relief cavity has indicated the existence of large property variations and significant regions of subsonic flow. These subsonic recirculating regions are essentially dead spaces in the cavity since mass is neither convected in or out of an area surrounded by a closed streamline. These regions are local hot spots since the temperature is approaching its stagnation value. Large pressure variations occurred in this cavity. (1:343–357)

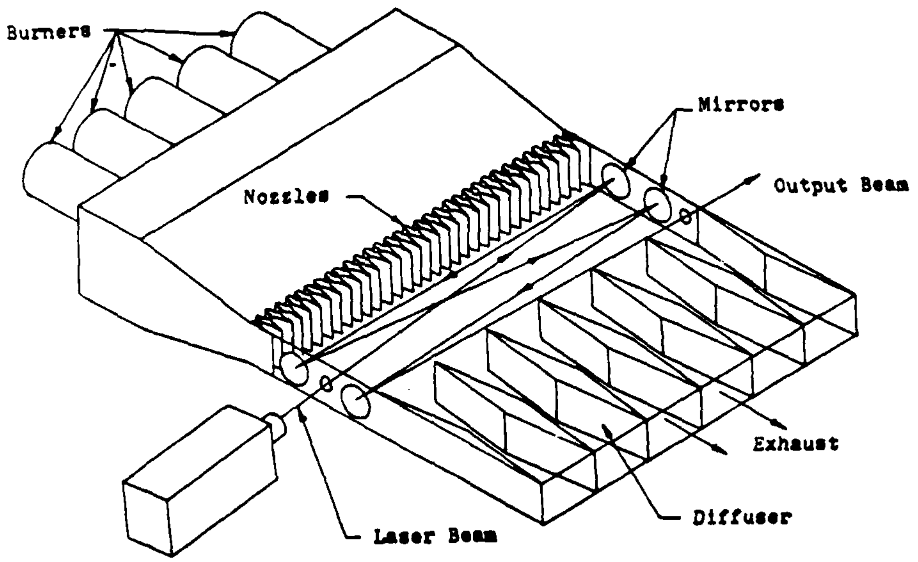

Figure 1.1. Schematic of a Chemical Laser Nozzle Assembly and Laser Cavity

Computer analysis, when supported by experimental results, should deepen the understanding of many complex flows associated with chemical lasers. From these statements, it is apparent that a great need for the experimental investigation of a chemical laser cavity flowfield exists.

1.2 Scope

Given the general schematic for a CL, shown in Figure 1.1, two areas of concern must be investigated. The first, and primary, area of concern is describing the flowfield in the cavity and its limitations under simulated laser operating conditions. Cold flow analysis techniques were used in conjunction with theoretical models to describe the cavity flowfield. The second concern is the design and configuration of the test apparatus required to support the test section. Pressure-vacuum wind tunnel technology was used to establish and maintain laser cavity-like conditions.

1.3 Objectives

The investigation has two major objectives:

1. To establish a facility capable of investigating flow conditions in a simulated laser nozzle assembly and lasing cavity.
2. Based on time history of pressures in the cavity and schlieren photographs of the cavity flowfield, determine the operating characteristics of the nozzle/cavity system.

The first objective was accomplished by modeling the nozzle and cavity design after current chemical laser nozzle and cavity designs, reconfiguring a current blowdown wind tunnel to permit simultaneous flow input from two sources, designing and fabricating a mixer and flow control system capable of providing a mixture of air and helium at various mass flow ratios, and designing and building a supersonic diffuser capable of maintaining the test section cavity at the low pressures required to start and maintain the required flow conditions.

The last objective was completed by a combined schlieren and static pressure analysis of the nozzle and cavity flowfield. One–dimensional analysis was used to describe the flow conditions in the nozzle region. A two–dimensional base–pressure model was used to analyze the flow conditions in the base region of the nozzle.

II. Theory

Analysis of the cavity flow conditions as a whole is nearly impossible with the complicated flow patterns and their interaction with each other. For simplicity, the flowfield is broken up into four logical regions, the nozzle, the base, the cavity, and the variable supersonic diffuser region. The conditions in the first region were analyized assuming one–dimensional steady, isentropic conditions. Schlieren photographs of the nozzle region showed no shock patterns or boundary layer separation that would preclude the use of the above mentioned assumptions. In the base region, however, the flow patterns start to become very complicated. The underexpanded flow stream exiting the nozzle goes through a Prandtl–Meyer expansion, and the flow is turned and accelerated. Jet boundary streamlines are formed indicating the boundaries of the accelerated flow stream. A multinozzle arrangement with a wide base region between nozzles creates an interaction between the flow streams so that when the accelerated flows meet wake regions are created along with oblique shocks and recompression regions. To handle the analysis of this complicated flow stream, the Korst Generalized Two–Dimensional Base-Pressure Model was selected (3:593–595). The cavity region flowfield is then a series of oblique shocks with wake and recompression regions. Static pressure measurements and schlieren photographs were used to describe the conditions in the cavity flowfield. Lastly, it was necessary to understand the flow mechanics in a supersonic diffuser so that one could be designed to help maintain the test conditions in the cavity for a longer period. Standard two–dimensional diffuser design procedures described by Hermann (4:136–169)were used to design the diffuser.

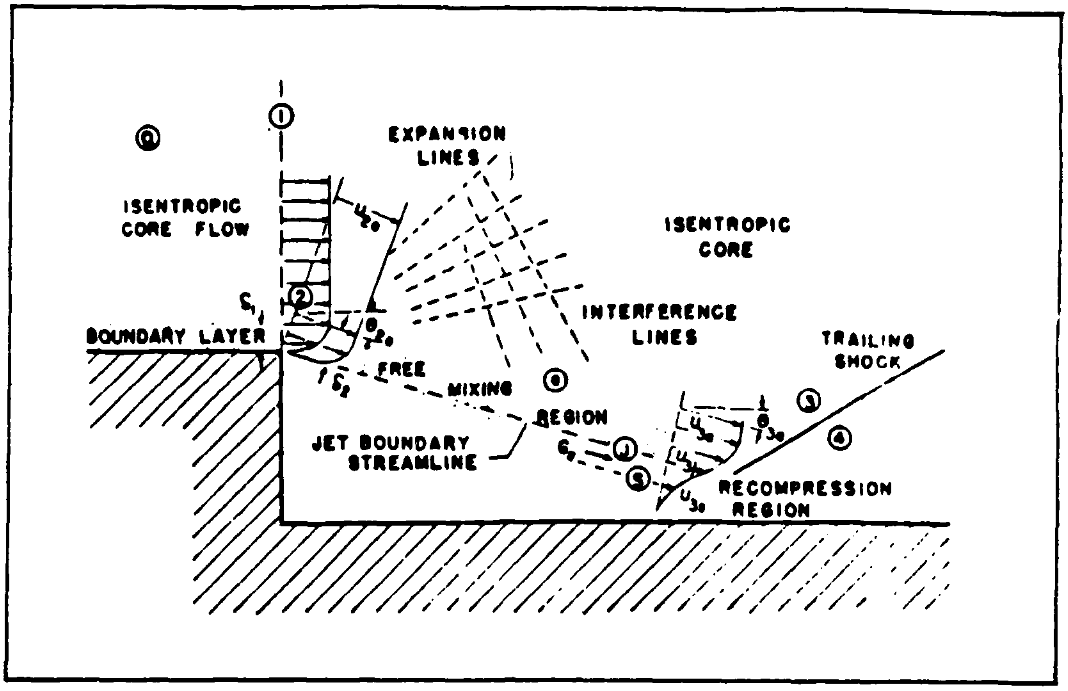

Figure 2.1. Flow Model for Two-Dimensional Base-Pressure Problem (3:594)

2.1 Nozzle Theory

One–dimensional converging–diverging (CD) nozzle theory described in Shapiro (5:76–105) is used to describe the flow conditions in the nozzle. More specifically, isentropic equations are used to calculate the conditions inside the CD nozzle.

2.2 Cavity Base Pressure Flowfield Analysis

Analysis of the cavity base pressures was handled by application of the generalized restricted theory to a closed wake region(3:593–599). Figure 2.1 shows the flow model. Using the generalized back-step method (3:597-599) for closed wakes and the flow configuration shown in Figure 2.2, an iterative technique is used to calculate flow conditions near the base, and the theoretical and experimental results are compared. The iterative procedure is detailed below:

1. Select M_{1a} and θ_{1a}. Where θ_{1a} is the streamline angle for M_{1a}.

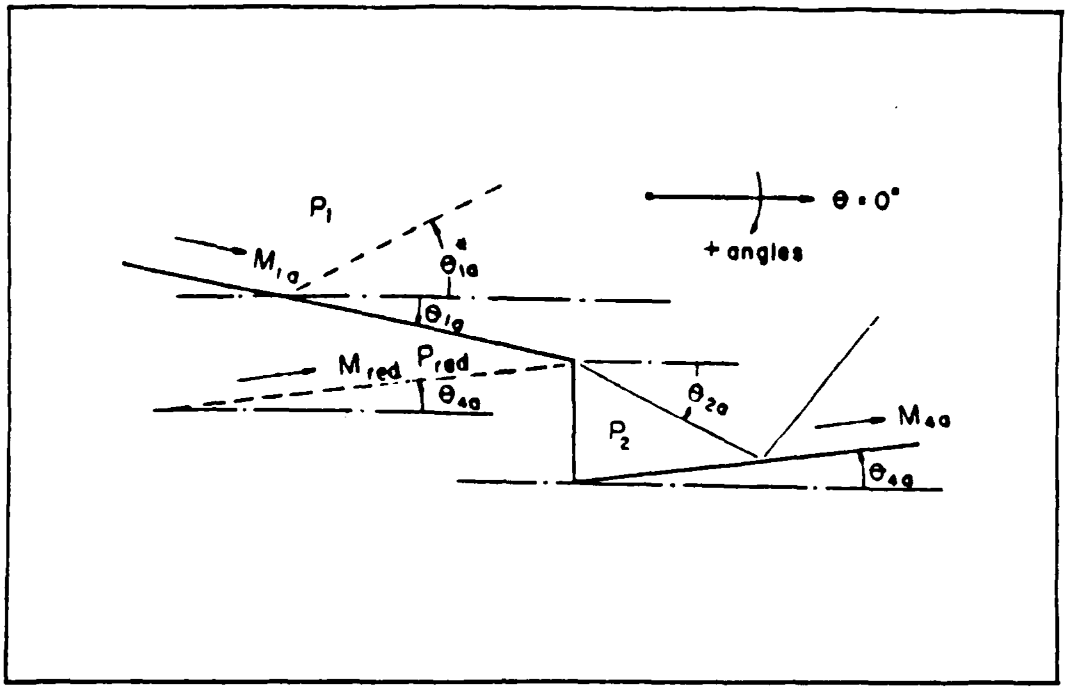

Figure 2.2. Flow Configuration for a Generalized Back Step Closed Wake Region (3:599)

2. Calculate ν_1 for M_{1a} Where ν_1 is defined as the Prandtl-Meyer function for M_{1a}.

3. Calculate ν_{red}. Knowing θ_{1a} and ν_1, ν_{red} can then be calculated using:

$$\nu_{red} = \nu_1 - \theta_{1a} \tag{2.1}$$

4. Calculate M_{red_t}. Using an iterative technique M_{red_t} can be calculated with the Prandtl–Meyer equation (6) shown below:

$$\nu = b^{.5} \arctan\left[\frac{(M^2-1)}{b}\right]^{.5} - \arctan{(M^2-1)}^{.5} \tag{2.2}$$

where

$$b = \frac{\gamma+1}{\gamma-1}$$

5. Guess an M_{2a}. Once M_{red_t} has been calculated, the problem is handled just like a basic back step problem. M_{2a} is selected close to M_{red_t} and the calculations are continued.

6. Calculate C_{2a} using:

$$C_{2a} = [1 + \frac{2}{(\gamma - 1)M_{2a}^2}]^{-.5} \tag{2.3}$$

where Crocco's number is

$$C = \frac{u}{u_{max}} \tag{2.4}$$

7. Calculate φ_j. Using:

$$\int_{\eta_J}^{\eta_R} \frac{\varphi d\eta}{1 - C_{2a}^2 \varphi^2} = \int_{-\infty}^{\eta_R} \frac{\varphi_2 d\eta}{1 - C_{2a}^2 \varphi_2} \tag{2.5}$$

where φ is called dimensionless velocity

$$\varphi = u/u_{2a} \tag{2.6}$$

An iteration scheme is applied solving for η_j where:

$$\varphi_j = \frac{1}{2}(1 + erf\,\eta) \tag{2.7}$$

and $\eta_R = 2$. The iteration technique described above was performed and a polynomial solution for φ_j as a function of C_{2a} was obtained. The polynomial equation is listed below:

$$\varphi_j = 3.15648\, C_{2a}^6 - 9.22972\, C_{2a}^5 + 11.047\, C_{2a}^4$$
$$-6.7842\, C_{2a}^3 + 2.31116\, C_{2a}^2 - 0.382329\, C_{2a} + 0.642023 \tag{2.8}$$

8. Calculate C_{3_j}. Combine Equations 2.4 and 2.6 to form

$$C_{2_j} = \varphi_j C_{2a} \tag{2.9}$$

Since $C_{3a} = C_{2a}$ then

$$C_{2_j} = \varphi_j C_{3a} \tag{2.10}$$

implying that

$$C_{3_j} = \varphi_j C_{2a} \tag{2.11}$$

9. Calculate M_{3_j} using:

$$M_{3_j} = [(C_{3_j}^{-2} - 1)\frac{\gamma - 1}{2}]^{-1} \tag{2.12}$$

10. Calculate $\frac{p_4}{p_3}$. From the escape criterion (3:596), it is known that fluid that has $\frac{p_{03}}{p_4} < 1$ will not be able to penetrate into region 4 and fluids where $\frac{p_{03}}{p_4} > 1$ will be able to pentrate region 4. With that in mind and the fact that a closed wake specifies that $\frac{p_{03_j}}{p_{03d}} = \frac{p_{03_j}}{p_4} = 1$

$$\frac{p_4}{p_3} = (1 + \frac{\gamma - 1}{2} M_{3_j}^2)^{\frac{\gamma}{\gamma - 1}} \tag{2.13}$$

11. Calculate θ_{2a}. From $\frac{p_4}{p_3}$, M_{2a}, and the oblique shock relationships $(\theta_{3a} - \theta_{4a})$ can be solved for using (7:11):

$$\theta_{3a} - \theta_{4a} = \arctan[(\frac{\xi - 1}{\gamma M_1^2 - \xi + 1})^2 (\frac{2\gamma M_1^2 - (\gamma - 1) - (\gamma + 1)\xi}{(\gamma + 1)\xi + (\gamma - 1)}]^{.5} \tag{2.14}$$

where

$$\xi = \frac{p_4}{p_3}$$

Since $\theta_{2a} = \theta_{3a}$ for a straight jet boundary then

$$\theta_{2a} - \theta_{1a} = \theta_{3a} - \theta_{4a}$$

12. Calculate ν_1 using:

$$\nu_1 = \nu_2 - \delta_{12} \tag{2.15}$$

13. Calculate M_{red_c}. Given M_{2a}, δ_{12}, and ν_1, M_{red_c}can be calculated using Equation 2.2 in a bi-section iterative technique. The resulting M_{red_c} is then compared with the earlier determined M_{red_t}, and if the two do not match, a new M_{2a} is selected and the process is repeated. The process is continued until the calculated M_{red_c} matches M_{red_t}.

14. Calculate $\frac{p_2}{p_1}$. Knowing M_{red_t} and M_{2a} and the isentropic pressure relationship listed below the ratio of $\frac{p}{p_0}$ can be calculated by:

$$\frac{p}{p_0} = (1 + \frac{\gamma - 1}{2} M^2)^{\frac{\gamma}{\gamma-1}} \tag{2.16}$$

Since the flow is assumed to be isentropic, the stagnation pressure p_0 is constant. Therefore, $\frac{p_2}{p_1}$ can be calculated by:

$$\frac{p_2}{p_1} = \frac{p_2}{p_{01}} \frac{p_{01}}{p_1} \tag{2.17}$$

15. Compare theoretical and experimental $\frac{p_2}{p_1}$. The calculated $\frac{p_2}{p_1}$ can now be compared to the experimental results. At this particular point, it should be noted that theoretical results are very sensitive to the original θ_{1a} selected. If θ_{1a} is not known accurately then it might be necessary to adjust θ_{1a}.

2.3 Supersonic Diffuser Theory

It is necessary to understand the shock patterns in a supersonic diffuser to determine the best wedge angle for the convergent section of the diffuser. The correct shock pattern will provide the best (higher) pressure recovery. To determine the correct shock pattern some of the diffuser geometry must be known and an optimization must be performed to calculate the wedge angle

that provides the best recovery pressure for the diffuser geometry selected. Diffuser theory was taken from Hermann (4:125–136). Appendix B lists the software program and some of the calculations necessary in the selection of a diffuser blade wedge angle.

III. Experimental Apparatus

The experimental apparatus is composed of three major components: the flow system, test section and the data acquisition/reduction system. A diagram of the system is shown in Figure 3.1. The flow system included the AFIT compressed air system, a horizontal stilling chamber, mixer, a variable supersonic diffuser, and the vacuum system. The new test section was built with one set of hypersonic nozzles and the side walls were made of optical plexiglass to allow the use of the schlieren flow visualization system. Instrumentation used to monitor the flow system was a Qua Tech multichannel simultaneous sampling system installed in the Zenith Z-248 computer and ENDEVCO pressure transducers . It should be mentioned that a flow system using helium and air was initially considered, but it was finally decided to use solely air during this research.

3.0.1 Flow System Considerable design and fabrication work was required to set up the new flow system for the blowdown wind tunnel. The newly designed mixer, designed and fabricated earlier when combined air and helium flows were being considered, was left in place in the horizontal stilling chamber. A supersonic diffuser was designed and fabricated to attempt to maintain the test section cavity pressures for an extended time, and finally, an extension to the existing vacuum system was built to finish the flow system.

3.0.1.1 Compressed Air System The compressed air system consists of two ATLAS COPCO Air Compressors, Model GAU-807, two DELTECH Filters, Model 819, two Pioneer Refrigerant Air Dryers, Model R550A, and two Arrow Compressed Air Dryers. Figure 3.2 shows the compressed air system configuration. Each of the air cooled compressors is capable of providing 520 standard cubic feet/minute (SCFM) at 102 pounds/square inch gauge (psig).

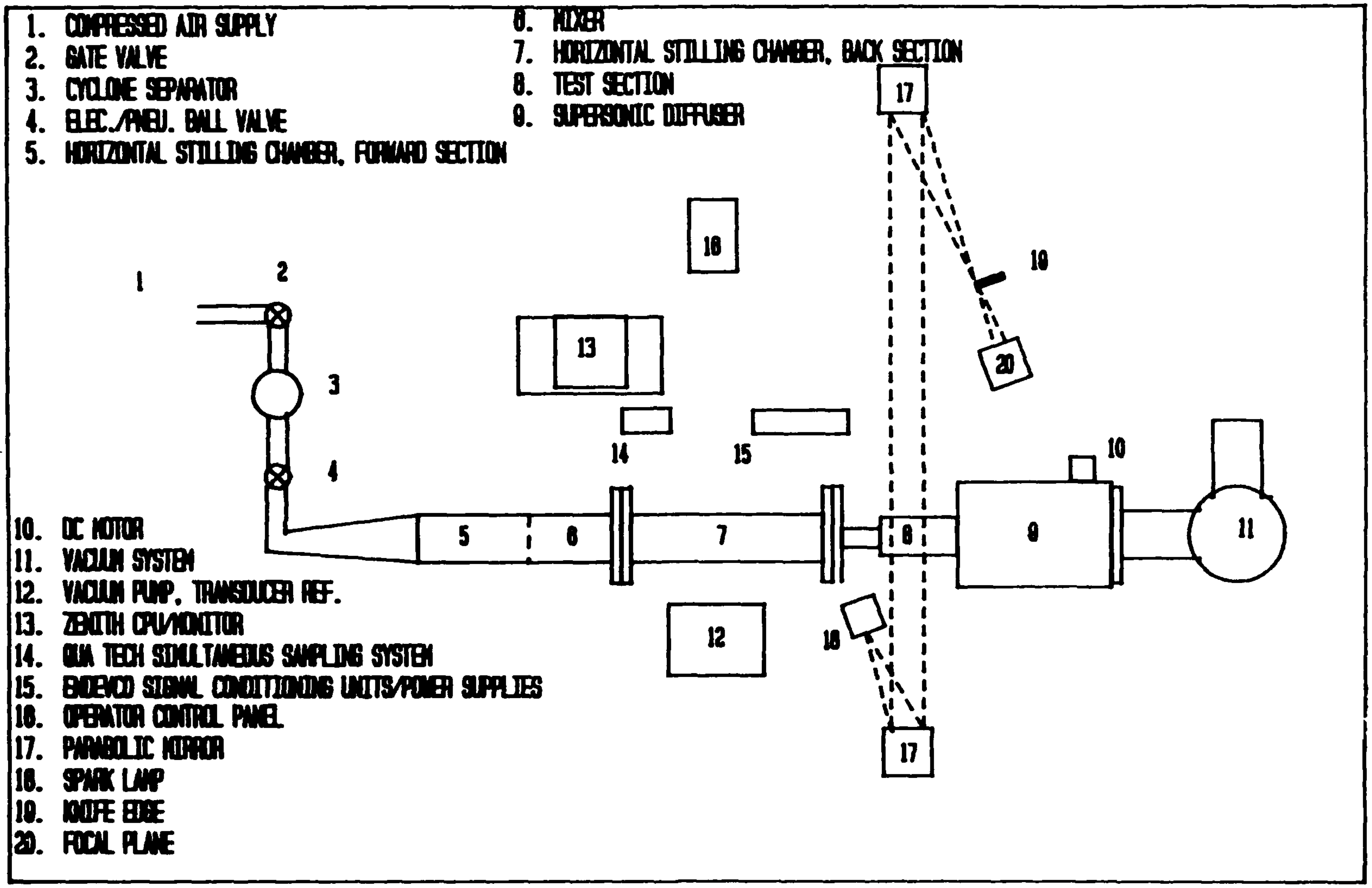

Figure 3.1. Equipment Apparatus Configuration

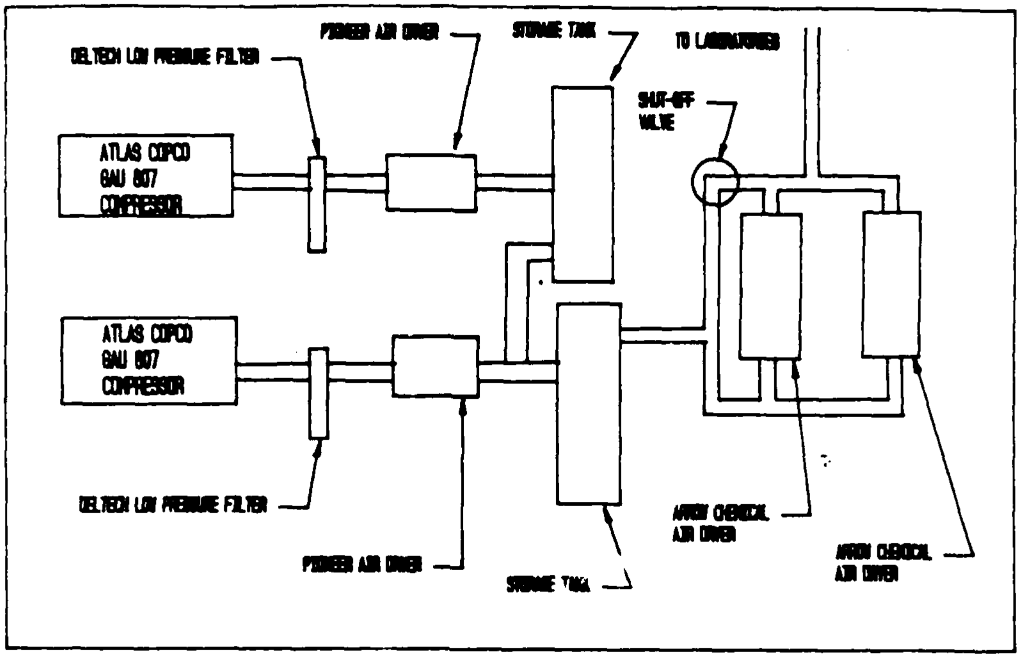

Figure 3.2. Building 640 Laboratory Compressed Air System

The DELTECH filters are used to eliminate any pollutants, such as oil, from the air flow. The Pioneer refrigerant air dryers eliminate moisture from the air flow and support a mass flow rate up to 500 SCFM. The calculated pressure loss across the refrigerant air dryers is approximately 3.6 psig. A second drying stage is available through the Arrow Chemical Air Dryers. Normally, the chemical air dryers are by–passed due to their large pressure loss, approximately 10 psig. Once the air flow is through the final stages of drying, it is piped to the laboratories. In the laboratory the air goes through a gate valve and into a cyclone separator. The cyclone separator is the final station used to eliminate particulate matter from the air flow. Next, the air is routed through an electrically controlled 3 inch ball valve. The Starlite model 666-F Ball Valve provides quick opening and the 3 inch ID provides the maximum air flow to fill the horizontal stilling chamber and start the nozzles.

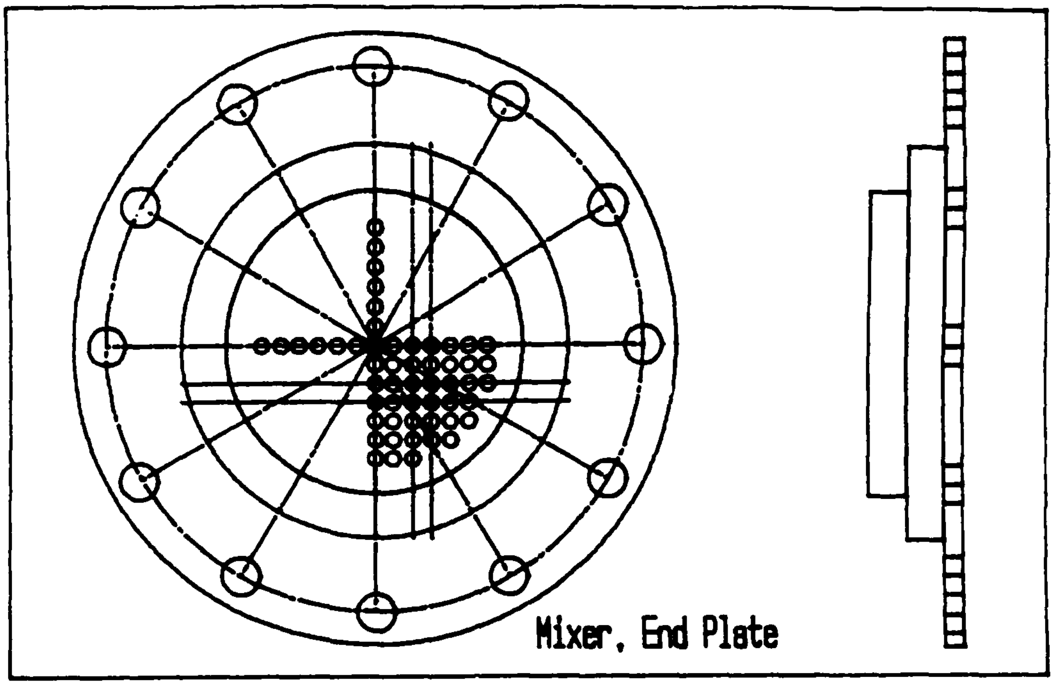

Figure 3.3. Mixer End Plate View

3.0.1.2 Horizontal Stilling Chamber The six foot horizontal stilling chamber is composed of two parts. The forward section houses a steel honeycomb mesh to help straighten and distribute the air evenly prior to it entering the mixer. The forward section, shown in Figure 3.1 also contains the mixer. The mixer provides no function in this investigation. The second section of the horizontal stilling chamber acts strictly as an air stilling chamber and contains no other devices other than pressure transducer taps.

3.0.1.3 Mixer The mixer design was based on the Vassilatos parallel multitube ejector design described by Zakanycz (8). The dimensions of the discharge end of the Vassilatos multitube ejector were enlarged so that a large scale version of the multitube ejector mixer could be placed inside the horizontal stilling chamber (see Figure 3.3). The mixer was made out of stainless steel tubing, plywood, plexiglass, 8 inch PVC, and aluminum plate. A side view of the mixer design is shown in Figure 3.4. The mixer slipped into the forward section of

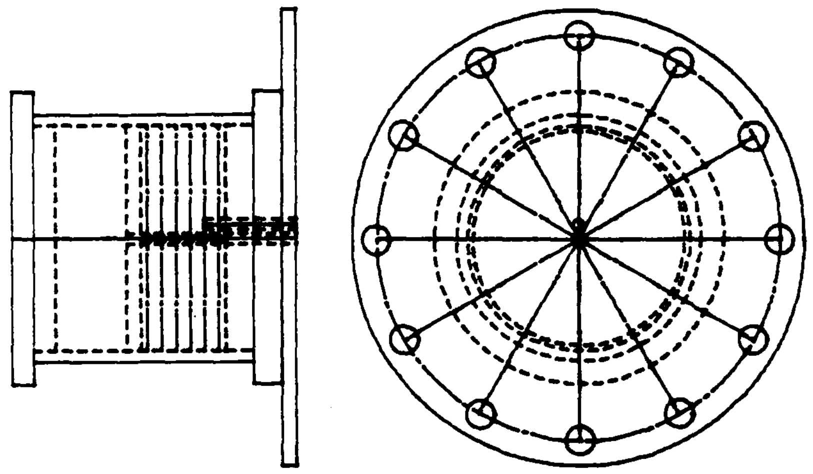

Figure 3.4. Mixer Side View

the horizontal stilling chamber. The flange end of the mixer was sandwiched between the flange ends of the forward and rearward portions of the horizontal stilling chamber. Air flow entered the forward portion of the horizontal stilling chamber from the end as indicated in Figure 3.1. The air flow first encountered a steel honeycomb mesh and then entered the mixer through the forward plate. Entering the mixer, the air was forced to flow around a chamber full of glass beads (marbles). The glass beads caused an even distribution of air to flow into the air tubes. A fine wire mess was placed between the glass beads and the entrance to the tubes to filter out any debris. Once in the tubes, the air was directed through the remaining part of the mixer and out the end plate.

The mixer was designed to receive flow from a second source which would enter a cavity formed by the fit of the mixer installed in the horizontal stilling chamber. The side wall of the mixer would deflect the second flow stream around the mixer and into the holes drilled in the side of the PVC. Once inside this cavity in the mixer, the second flow was forced to flow around the air

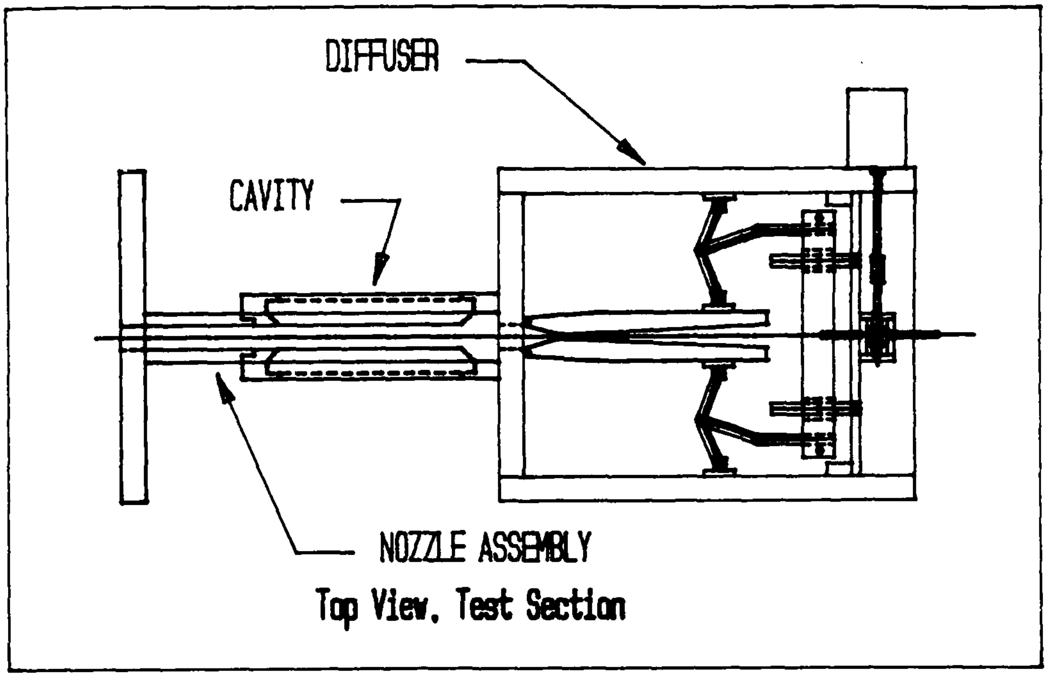

Figure 3.5. Test Section, Top View

tubes traversing the cavity, into a second set of tubes, and then directed out the end plate. The alternating of the primary/secondary tubes exiting the end plate would induce a thorough mixing in the rearward portion of the horizontal stilling chamber. As indicated above, a second flow source was not used in this investigation.

3.0.1.4 Variable Supersonic Diffuser A supersonic diffuser was built to maintain the low pressures in the cavity portion of the test section. The diffuser was made out of aluminum and plexiglass and actuated by a 24 v dc Delco motor. Figure 3.5 displays the mechanisms required to vary the diffuser dimensions. The blades of the diffuser open perpendicular to the direction of expansion from the nozzles. This unique design was adopted to minimize the length of the diffuser section. The dc motor, see Figure 3.5 was electrically controlled from the operator control panel. Power for the motor was provided by the laboratory dc power supply, a Rapid Electric Co. Model S-528. The motor,

shown in Figure 3.6, mounted on the outside of the diffuser enclosure, drives a shaft that penetrates the diffuser side wall through a pressure tight seal. The shaft drives a gearing mechanism that turns a threaded shaft. The threaded shaft moves back and forth either pushing or pulling the diffuser slide bracket. Adjustment contacts positioned on the thread shaft deactivate the motor when the contact bars close the micro-switches mounted on the adjustment bracket behind the gearing mechanisms.

3.0.1.5 Vacuum System To establish the desired test section operating conditions it was necessary to have high pressure on one end of the wind tunnel and a vacuum on the other end. The vacuum system consists of 16 large tanks suspended from the laboratory and three vacuum pumps. Two of the three vacuum pumps are Leiman, no model number, radiator cooled pumps, and the third pump is a Stokes, Model 212-H. The Stokes pump has the capacity to pump 140 SCFM. The 16 vacuum tanks, along with the piping, provide approximately 650 ft^3 of vacuum space. A network of 8 inch PVC pipe connected the test section to the vacuum system. The interface between the PVC pipe and the test section was a Consolidated Vacuum Corporation, Model VCS-41, high vacuum valve. The high vacuum valve allowed the operator to isolate the wind tunnel from the vacuum system. A Meriam U-tube mercury manometer, Model 20DA40, was incorporated to provide the operator with the vacuum pressure readings while the tunnel is being evacuated.

3.0.2 Test Section The test section was designed to simulate current chemical laser primary nozzle and cavity designs. The test section was constructed out of aluminum and the windows were cut from 1 inch thick optical plexiglass. Figure 3.7 shows the nozzle assembly/cavity/diffuser arrangement of the test section.

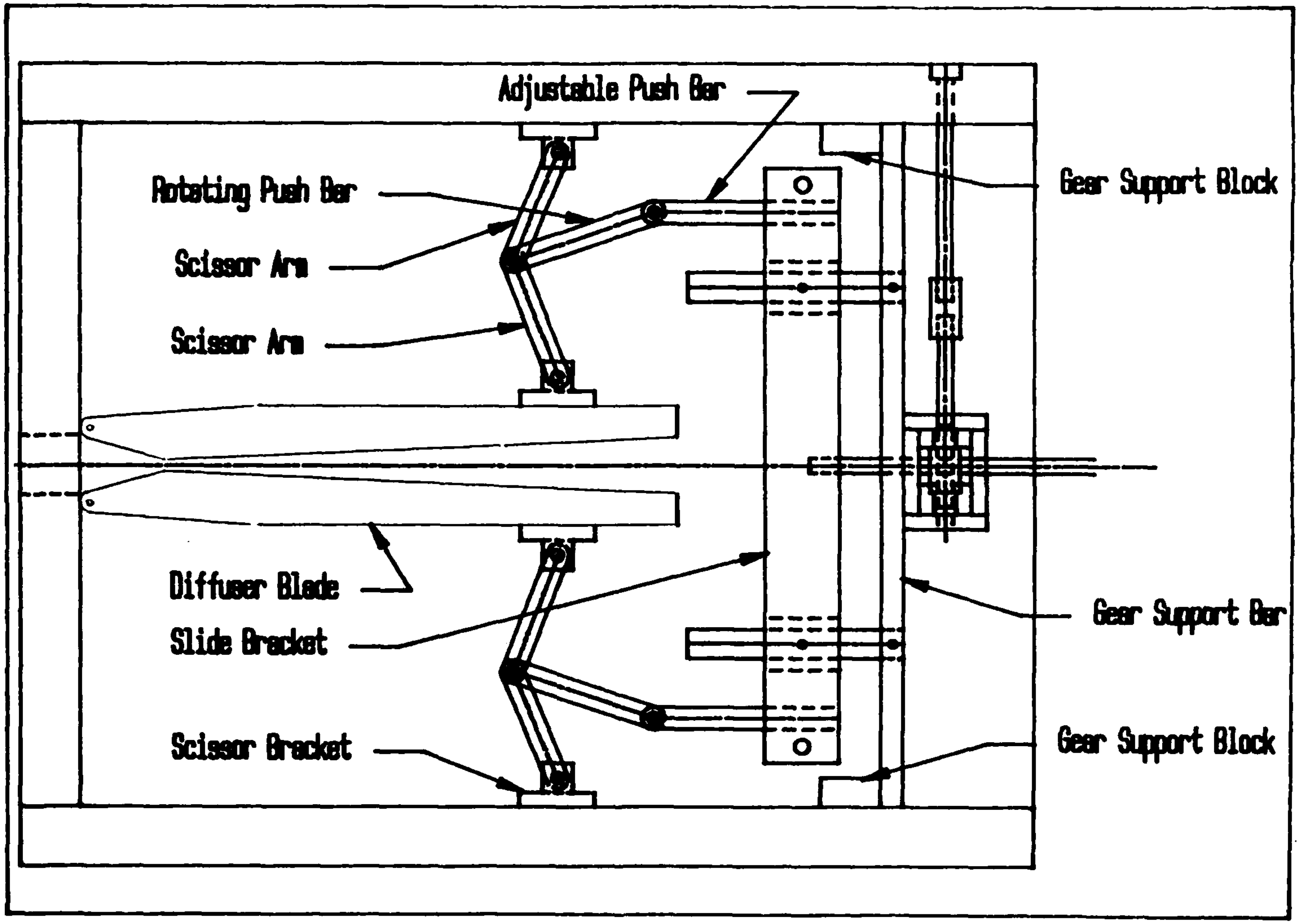

Figure 3.6. Variable Supersonic Diffuser, Top View

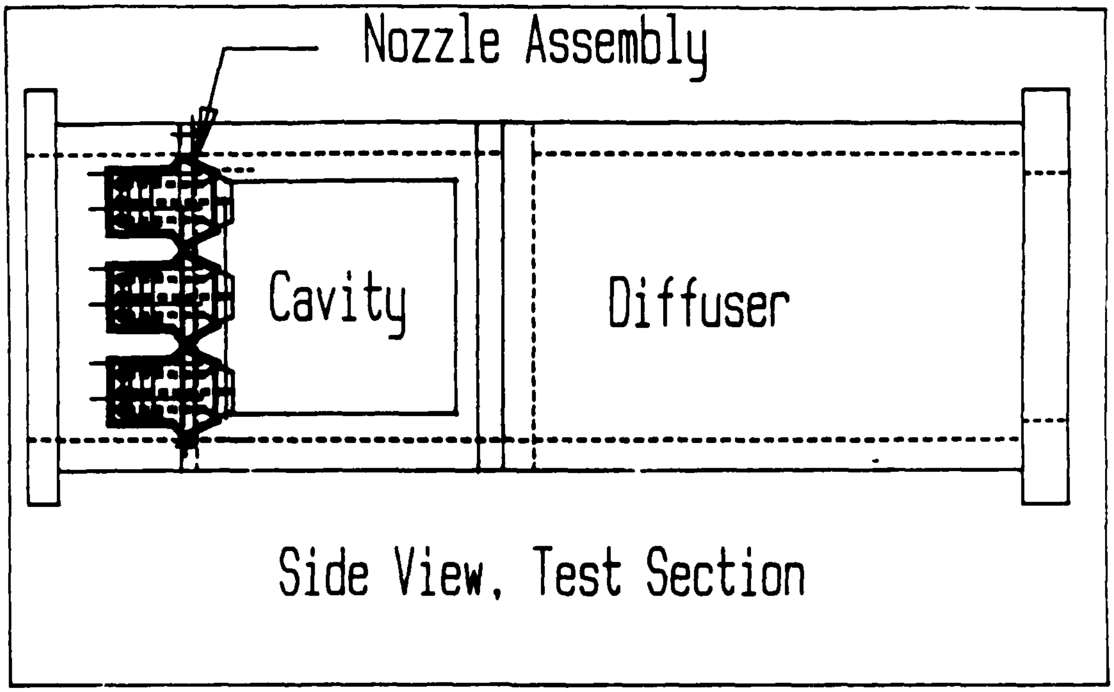

Figure 3.7. Test Section, Side View

3.0.2.1 Nozzles The nozzle/cavity design selected and its general operating conditions were established from information provided by the Air Force Weapons Laboratory (AFWL) (9), Kirtland, NM. Figure 3.8 shows the contour of the nozzle and Table 3.1 (10) lists the dimensions of the nozzle contour. The nozzle design parameters are listed in Table 3.2. Figure 3.9 displays the three primary wedges as they are mounted in the test section. The current design allows enough material to machine the base region to accommodate modifications for future testing. Three pressure ports, shown in Figure 3.9 were drilled into each of the primary wedges to allow static pressure measurements in the region of the base and the nozzle exit plane.

3.0.3 Data Acquisition and Reduction System The data acquisition system is a group of interconnected electronic instruments used to measure and evaluate pressure variables produced in the flow stream. The data reduction system is a software controlled digital computer that processes and analyzes the col-

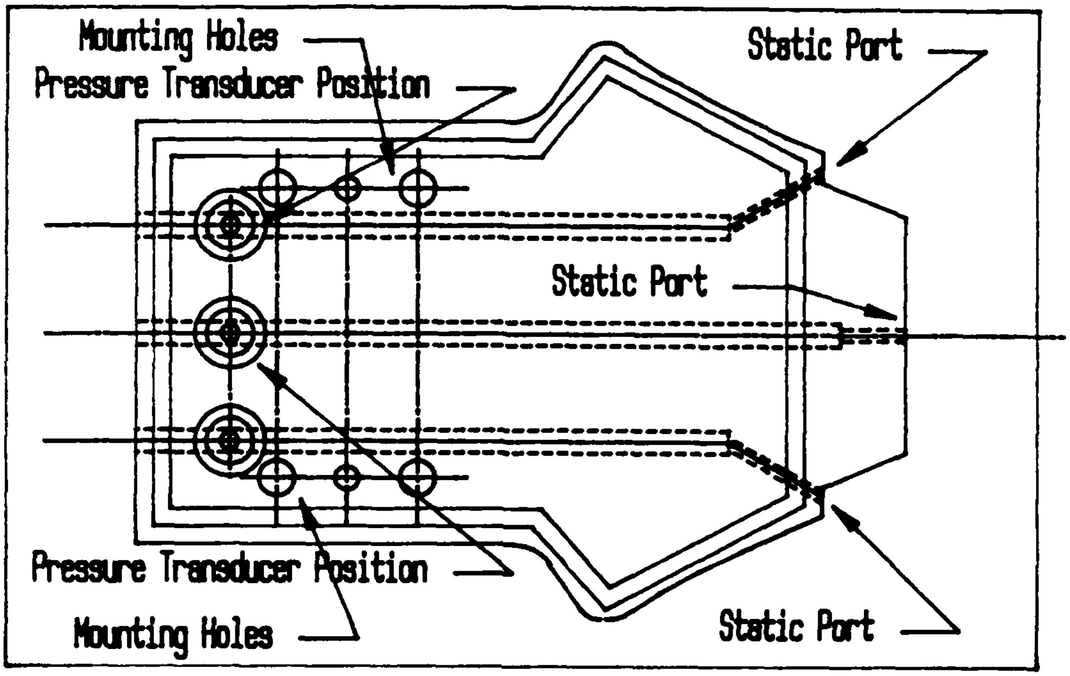

Figure 3.8. Nozzle Contour

Table 3.1. Nozzle Contour Position

	X Position	*Y Position*
1	0.0000	0.0000
2	0.0013	0.0240
3	0.0055	0.0480
4	0.0204	0.0960
5	0.1429	0.2880
6	0.2604	0.5040
7	0.3657	0.7200
8	0.4742	0.9600
9	0.5560	1.1530

Table 3.2. Nozzle Design Parameters

Variable	*Quantity*
γ	1.51
P_0	100.0 psia
T_0	73 F
M_e	6.00
P_e	0.104 psia
T_e	7.2 F
A_e/A^*	28.8

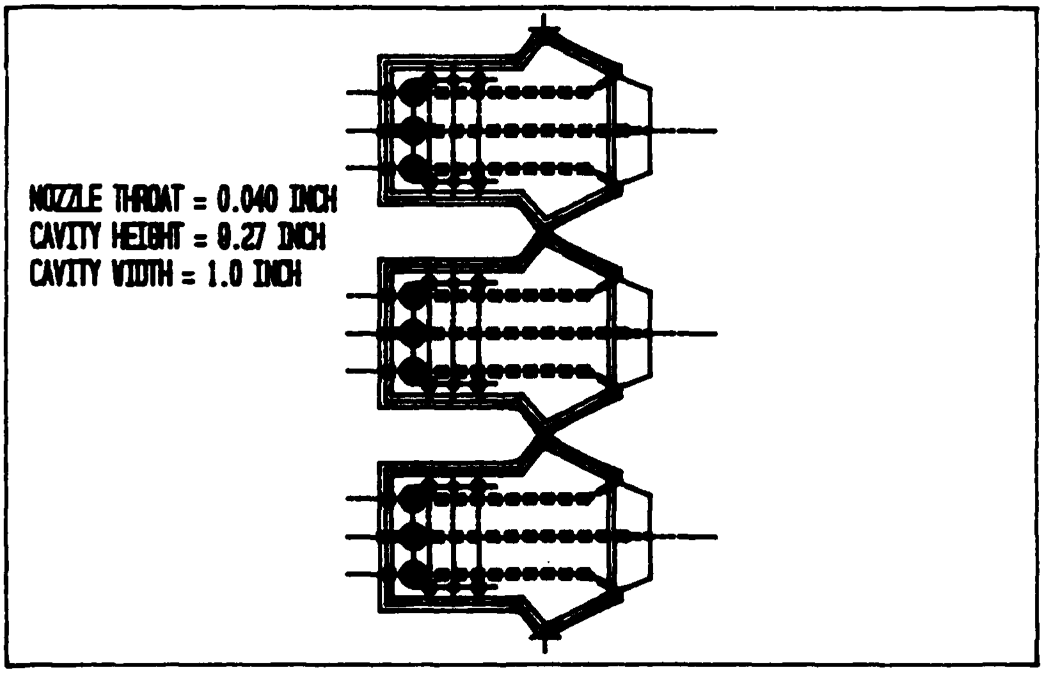

Figure 3.9. Primary Wedge Configuration

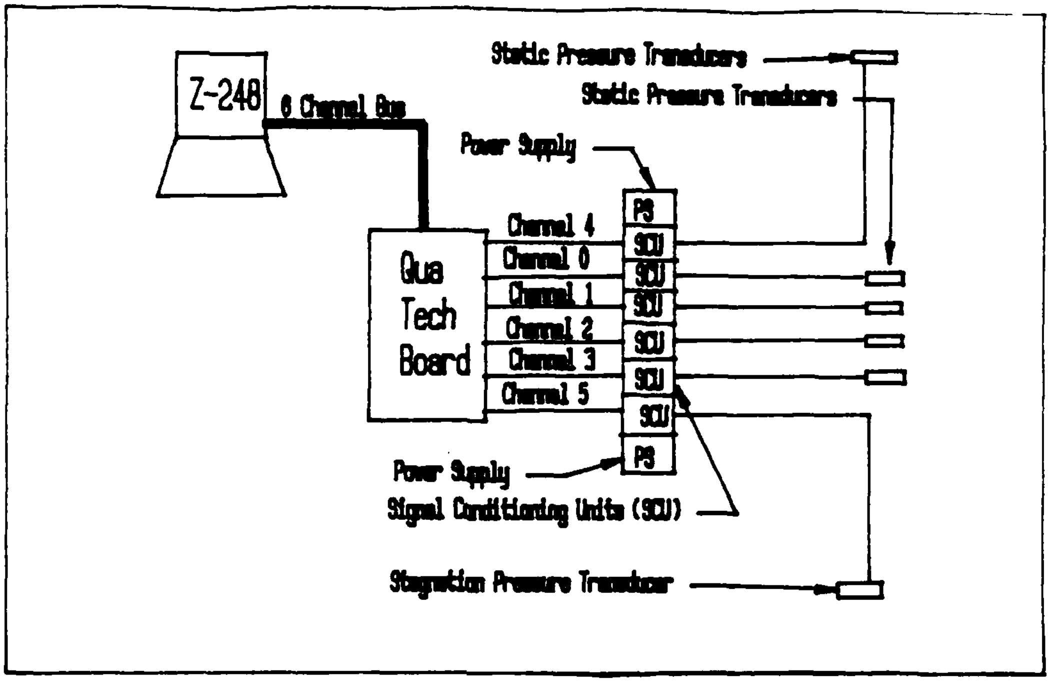

Figure 3.10. Data Acquisition System

lected data. The Data Acquisition and Reduction System DARS is made up of several basic components. A block diagram of this system is shown in Figure 3.10. The Zenith Computer System, the heart of the DARS, controls the data acquisition and reduction process through a combined Qua Tech and operator written Quick Basic software program. The analog signal from the piezoresistive pressure transducer is passed to the Qua Tech Multichannel Simultaneous Sampling System installed in the Zenith Computer Processing Unit CPU . The Qua Tech sampling system allows the DARS to monitor six channels simultaneously.

3.0.3.1 ENDEVCO Piezoresistive Pressure Transducers Miniature piezoresistive pressure transducers with highly sensitive strain gauges mounted in a silicon diaphragm were used to monitor the flow stream. ENDEVCO piezoresistive pressure transducers placed in the flow stream converted pressure data to electrical analog signals. Pressure measurements were taken at twenty-four

Table 3.3. Pressure Transducer Signal Conditioning Unit Assignments

SCU	*Model Number*	*Serial Number*
1	8510B-5	PP81
2	8510B-5	79HB
	8506B-5	92BF
3	8510B-5	78HB
	8506B-5	74BF
4	8506B-5	68BF
5	8510B-15	9BYP
	8506B-5	79BF
6	8510B-100	35DF

positions throughout the flow system and the test section. Four different sizes of pressure transducers were used. One ENDEVCO pressure transducer, Model 8510B-100, was placed in the side wall of the horizontal stilling chamber, see Figure 3.11,upstream of the test section, to monitor stagnation pressure. Three ENDEVCO pressure transducers, Model 8510B-5, were used in the nozzle section to monitor static pressure, and four ENDEVCO pressure transducers, Model 8506B-5, were used in the test section plexiglass side walls to also monitor static pressure. One ENDEVCO pressure transducer, Model 8510B-15, was placed in the side wall of the vertical stilling chamber to monitor the back pressure. Pressure transducer specifications can be found in Reference 12. The locations of the twenty-four pressure taps are shown in Figure 3.11. Since a six channel data acquisition system was used, only combinations of six positions could be measured during any one test run. Table 3.3 lists the model and serial number of the transducers used on a particular signal conditioning unit (SCU).

3.0.3.2 ENDEVCO Signaling Conditioning Units/Power Supplies Two ENDEVCO Model 4225 ac-operated power supplies were used to provide $\pm$ 18 volts to the six ENDEVCO Model 4423 signal Conditioning units. The signal

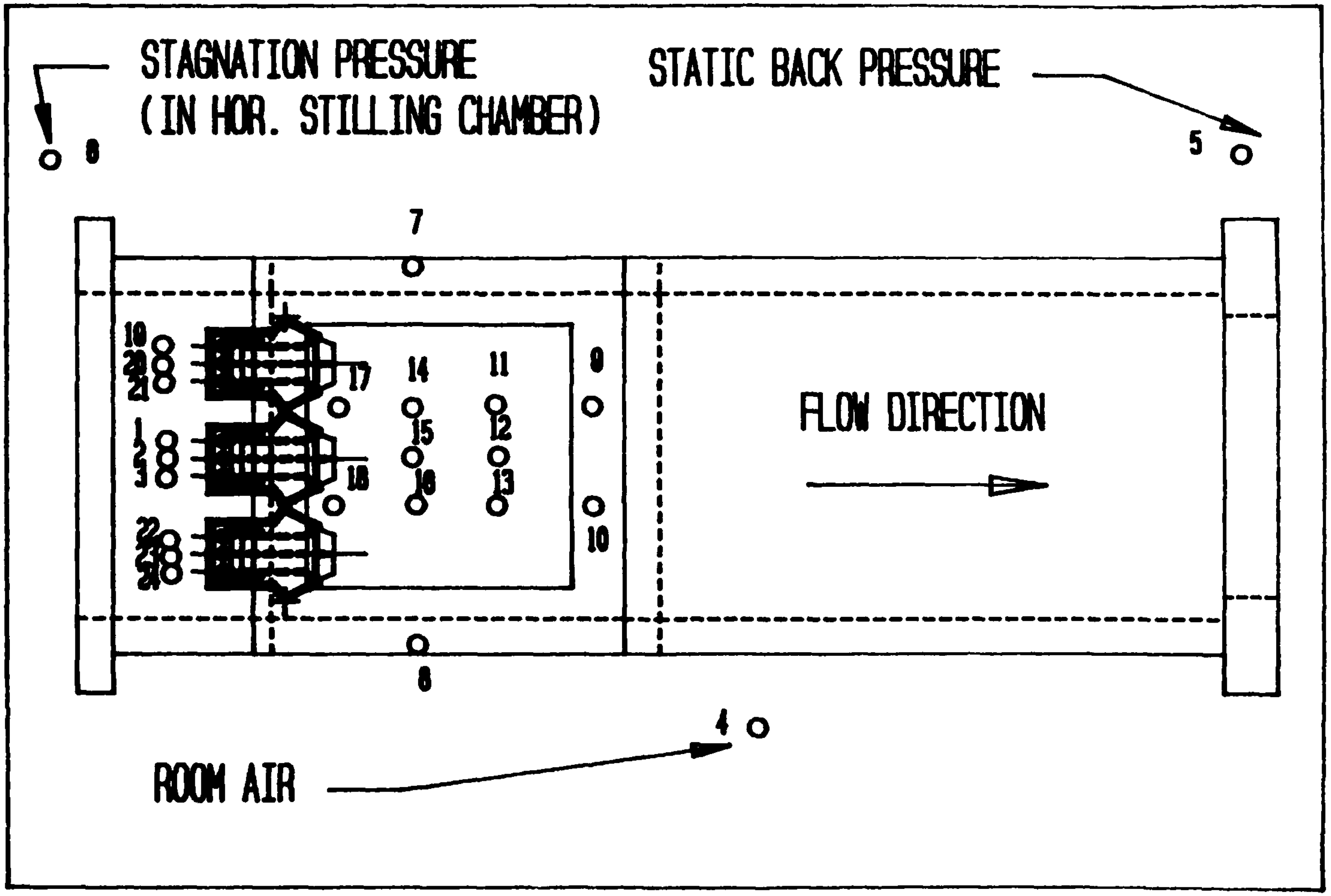

Figure 3.11. Pressure Transducer Locations

conditioning units provide excitation voltage to the pressure transducer and amplify output voltage from the pressure transducers. Various fixed gain settings are front panel selectable and were used to match the input voltage range of the Qua Tech multichannel simultaneous sampling system.

3.0.3.3 Qua Tech Multichannel Simultaneous Sampling System The Qua Tech multichannel system provides six channels of simultaneous sampling. The six channel system contains three PXB-721 parallel expansion boards, six ADM12-11 12 bit analog-to- digital (A/D) converter modules, one CTM-11 counter/timer module , and one SS-INT interface board. An input voltage range of $\pm$ 2.5 volts was selected. The amplified analog signal was sampled at the operator specified sample rate and the sampled data was converted to an digital format by the A/D card. The digital signal was routed to the computer CPU over the computer system internal wiring system.

3.0.3.4 Zenith Computer System The two main purposes of the computer system are data acquisition and data reduction. The Zenith Computer System consists of one Zenith CPU, Model Z248, and one Zenith EGA Color Monitor, Model ZVM-1380. The CPU houses a 20 M hard drive, a 360 k floppy disk drive, a 1.2 M floppy disk drive, a math co-processor and 640 k of RAM. Qua Tech "LABSIM" software is combined with an operator written Quick Basic software program to control data acquisition and data reduction. The combined software package and its use is shown and described in Appendix A.

3.0.4 Schlieren Optical System Schlieren photographic equipment was used to capture the flow characteristics in the test section cavity. The equipment configuration is shown in Figure 3.12 and the equipment description is given in Table 3.4.

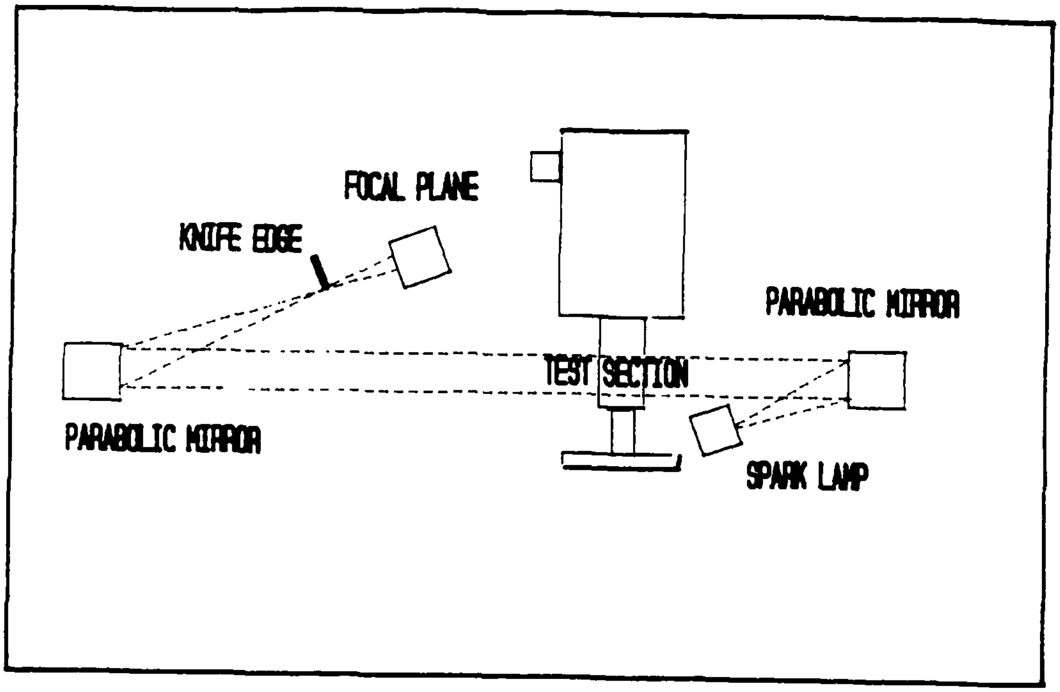

Figure 3.12. Schlieren Equipment Configuration

Table 3.4. Schlieren Equipment Data

Item	*Model Number*
Spark Lamp	Cordin Model 5401
7.5 inch Diameter Concave Mirrors	
Spark Lamp Power Supply	Cordin Model 5205
Trigger D.C. Power Supply	Hewlett Packard (HP)Model 6205B
Knife Edge	
Polaroid Camera	
Polaroid Film Holder	Polaroid Model 545

IV. Experimental Procedures

Procedures established to ensure accurate data collection cover calibration of instrumentation, data acquisition and reduction procedures, and Schlieren photograph procedures.

4.1 Pressure Transducer Calibration

AMETEK, Pnuematic Dead Weight Testers, Model PK-2 (low pressure, 300 inches of water) and Model HK-500 (high pressure, 500 psig), were used to calibrate the ENDEVCO piezoresistive pressure transducers. The test configuration is shown in Figure 4.1. The manufacturer of the pnuematic dead weight testers cautions that the use of any gas with the dead weight testers other than clean compressed air or nitrogen could cause discrepancies in the calibration data (13). The pressure transducers were calibrated with the ENDEVCO SCU in line. The ENDEVCO SCU has four gain settings 5, 10, 20, 50 and a bridge balance adjustment screw. Since the ENDEVCO SCU does not have a unity gain setting, it will always multiply the pressure transducer output voltage by some factor depending on which gain setting has been selected. The gain factors were not exactly as indicated on the front panel; therefore, the pressure transducers were calibrated with the SCU in line so that the exact gain factor is included in the slope of the calibration curve. The calibration curves of the pressure transducers used in this research are presented in Appendix B.

4.2 Data Collection

Two methods of data collection were used: data acquisition and reduction of pressure measurements, and schleiren photographs of the flowfield.

4.2.1 Data Acquisition and Reduction Procedures Data acquisition and reduction is controlled by the operator software described in Appendix B. The

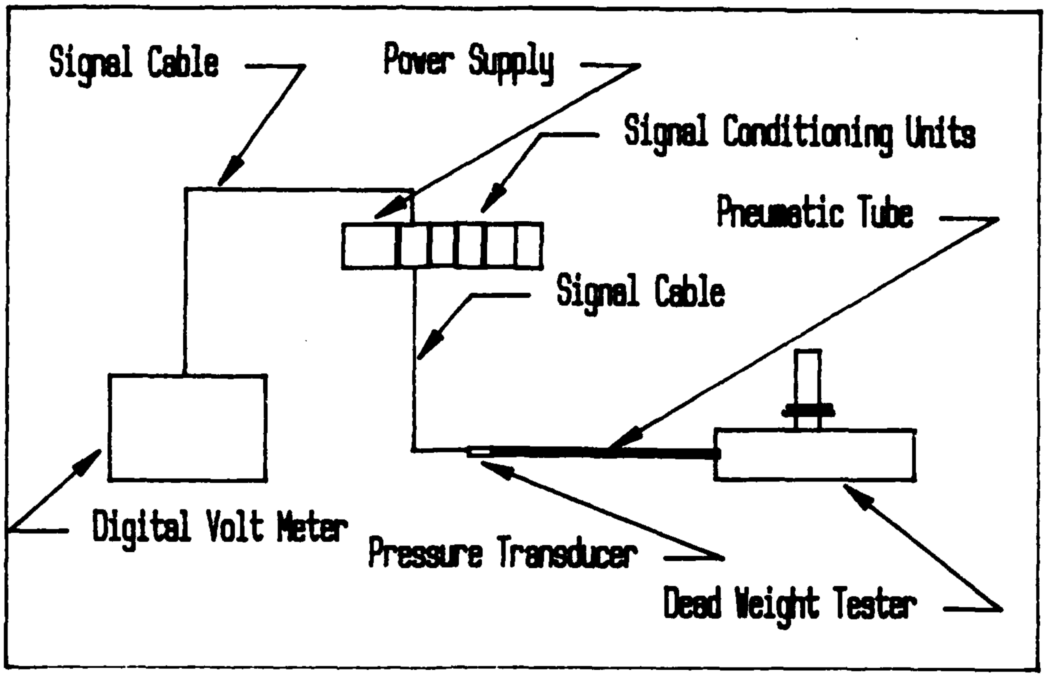

Figure 4.1. Pressure Transducer Calibration Setup

software has three distinct sections. The first section handles data acquisition. The second section handles data reduction, and the third provides a visual look at the converted data on the monitor screen. Each section walks the operator through the procedures necessary to complete the operation. See Appendix B for more details.

4.2.2 Schlieren Photograph Procedures Schlieren photographs were used to record the visual representation of the flow conditions in the test section cavity. Photographs were taken at specific times during the test runs. Pictures were then compared to the flow data collected by the DARS. The actual procedures for setting up and operating schleiren photographic equipment are described in AGARDograph No 23 (14:13-15).

V. Results and Discussions

The flow system consisted of a primary source of air fed into a pressure–vacuum wind tunnel test section through a mixing device. Once through ·ıe test section the air flow was routed through a supersonic diffuser, and emptied into a vacuum system. System evaluation included vacuum performance, diffuser performance, and test section (nozzle/base/cavity) performance.

5.1 Flow System Equipment Performance

The complete installation with controls and instrumentation was tested to determine its suitability to simulate the necessary laser nozzle/cavity operation. The system was able to pull a vacuum down to 0.1 psia. With the vacuum pumps turned off and the vacuum system closed, the vacuum was maintained at 0.1 psia for approximately 1 hour.

The variable supersonic diffuser needed to maintain the low cavity pressures was designed using two-dimensional theory. Diffuser theory indicated that the optimum starting and minimum running throat area ratios for a diffuser with an entrance Mach number of 5.0, should be 0.6 and 0.2, respectively. Experimentally, the optimum starting and minimum running throat area ratios were never established. Data runs indicate that the minimum running area ratio was much higher than the theoretical value. The minimum diffuser throat area ratio that allowed the full starting of the nozzles and held a steady static pressure at transducer positions 17 and 18 was determined to be 0.625. Diffuser area ratios above 0.625 also allowed the starting of the nozzles but failed to maintain the lower pressures for as long as the 0.625 diffuser throat setting. Throat areas below the 0.5625 setting do not allow the nozzle flow to fully expand in the cavity and in some cases cause separation in the nozzle divergent section.

It was initially intended that the flow testing would be done with an air/helium mixer, but it was later decided to do the initial testing using strictly air. Even though the mixer was not used for its intended purposes, it was still placed in the flow stream. Pressure across the mixer was monitored and no pressure drop was observed. Once the major components were in place, an electrically controlled ball valve was used to quickly turn the air flow on and off. Testing indicated that the horizontal stilling chamber reached maximum pressure in approximately 2 seconds.

5.2 Test Section Performance

The test section cavity flowfield conditions were investigated using two techniques, schlieren photography and static pressures measurements. Photographs, as well as pressure measurements, were taken with various supersonic diffuser throat areas. Examples of two of the test flow runs are shown in Figures 5.1 and 5.2. Close inspection of the photographs will show a multitude of fluid dynamics interaction such as boundary layers by the side walls of the nozzles, wakes and shock reflections along the base centerline, and jet streamlines extending from the exit of the nozzle to the base centerline. All the flow conditions mentioned, and even some that were not mentioned, have an effect on the accuracy of the experimental data. For this reason, the analysis was broken up into three areas, the nozzle, the base, and the open cavity section. Detailed investigation of the flow in the diffuser was not accomplished.

To start the investigation of the flowfield in the cavity, a series of schlieren photographs were taken. The photographs were used to select locations for pressure transducers in the test section plexiglass sidewall based on observed wakes and shock wave positions. Pressure transducers were also located in the horizontal stilling chamber and downstream from the diffuser to provide both static and stagnation pressure readings. Nine other pressure transducer

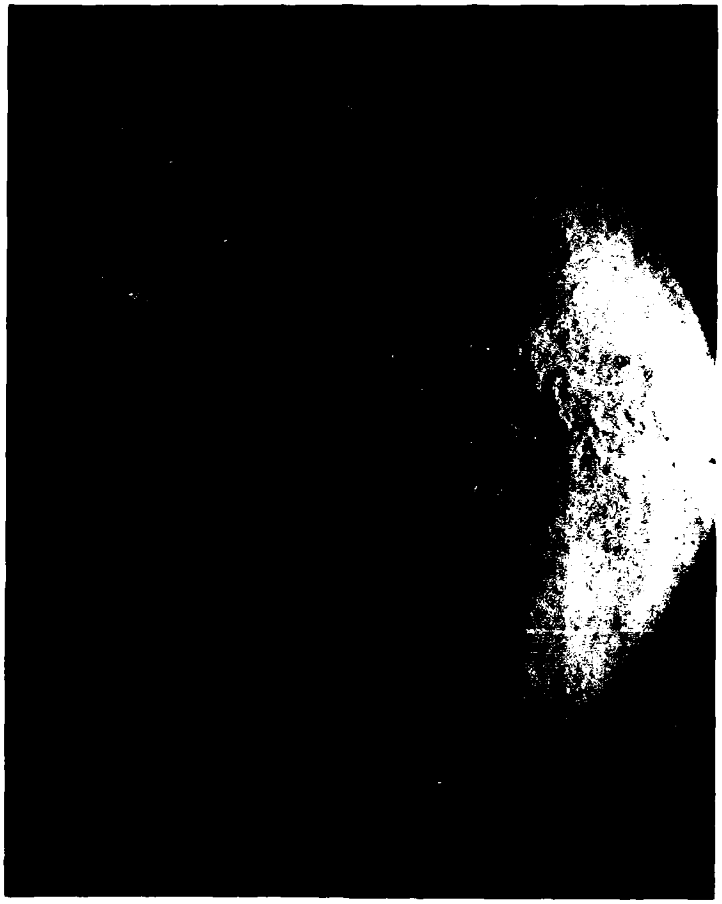

Figure 5.1. Cavity Flowfield, Diffuser Throat Setting of 0.6875 inches

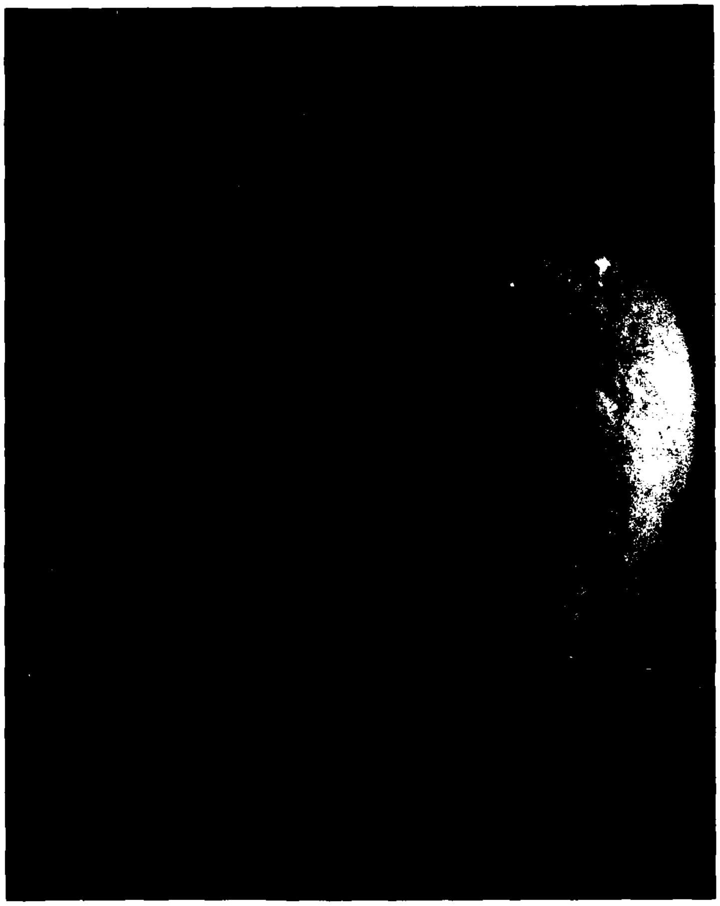

Figure 5.2. Cavity Flowfield, Diffuser Throat Setting of 0.625 inches

Figure 5.3. Cavity Flowflield, Diffuser throat setting of 0.75 inches

taps were built into the nozzle design, three taps per nozzle, to provide additional static pressure readings. Figure 3.11 provides a complete picture of the exact pressure transducer locations. Figures 5.3–5.6 show the flowfields with the supersonic difusser throat set at 0.75, 0.6875, 0.625, and 0.5625 inches, respectively.

5.2.1 Nozzle Flowfield Analysis The design parameters of the nozzle are listed in Table 3.2. From Figures 5.3–5.6, it can be seen that the exit conditions from the suppersonic nozzle seem to be shock free. For this reason, the analysis of the nozzle was handled using general one-dimensional, steady, isentropic flow. The nozzle was designed to operate with a γ of 1.51, but this intial series of testing used strictly air, so it was necessary to recalculate the exit Mach number (M_e)of the nozzle. Using the A_e/A^* of 28.8 and a γ of 1.4 the new M_e was calculated to be 5.18. The horizontal stilling chamber sidewall

Figure 5.4. Cavity Flowflield, Diffuser throat setting of 0.6875 inches

Figure 5.5. Cavity Flowfield, Diffuser throat setting of 0.625 inches

Figure 5.6. Cavity Flowflield, Diffuser throat setting of 0.5625 inches

pressure, taken prior to the test section, was considered to be a stagnation pressure due to the low velocities in the horizontal stilling chamber. Using the static pressure taps located at the exit of the nozzles, see Figures 5.3–5.6, and the stagnation pressure, the exit Mach number for all four diffuser throat settings was calculated and is shown in Figures 5.7–5.10. The exit Mach numbers are all very close to the theoretical value of 5.18 which indicates that the assumption of one–dimensional, steady, isentropic flow was correct. The Mach number falloff shown in Figures 5.9–5.10 is caused by the increase in static pressure at the nozzle exit plane, which is brought on by the less efficent diffuser throat area setting.

5.2.2 Base Flow Region Analysis Analysis of the flowfield after the nozzle exit is more complicated than the one-dimensional analysis used in the nozzle section. Figures 5.3–5.6 show various flow conditions depending on the value of the diffuser throat area. Close to the exit, though, and in the base region it is possible to use the two-dimensional Korst theory (3:593–599) to calculate base pressures and Mach numbers further down stream of the exit. To use the Korst theory, a M_{1a} and θ_{1a} must be selected. The experimental Mach number calculated by the static pressure at the exit of the nozzle was used as M_{1a}. The flow stream angle, however, is not quite as easy. From the method of characteristics, it can be shown that the flow stream angle varies from zero to the maximum deflection starting at the centerline and moving out to the edge of the nozzle (see Figure 5.11). Additionally, the Mach number varies from a minimum to a maximum starting at the nozzle centerline. To compare the experimental results with a theoretical value it was first necessary to determine the theoretical mass averaged flow stream angle. Since the divergent section of the nozzle has a slope of approximately twenty–six degrees, the flow stream angle should be somewhere between 0 and 26 degrees. Since the Mach number increases towards the outside edge of the nozzle, the mass flow rate would

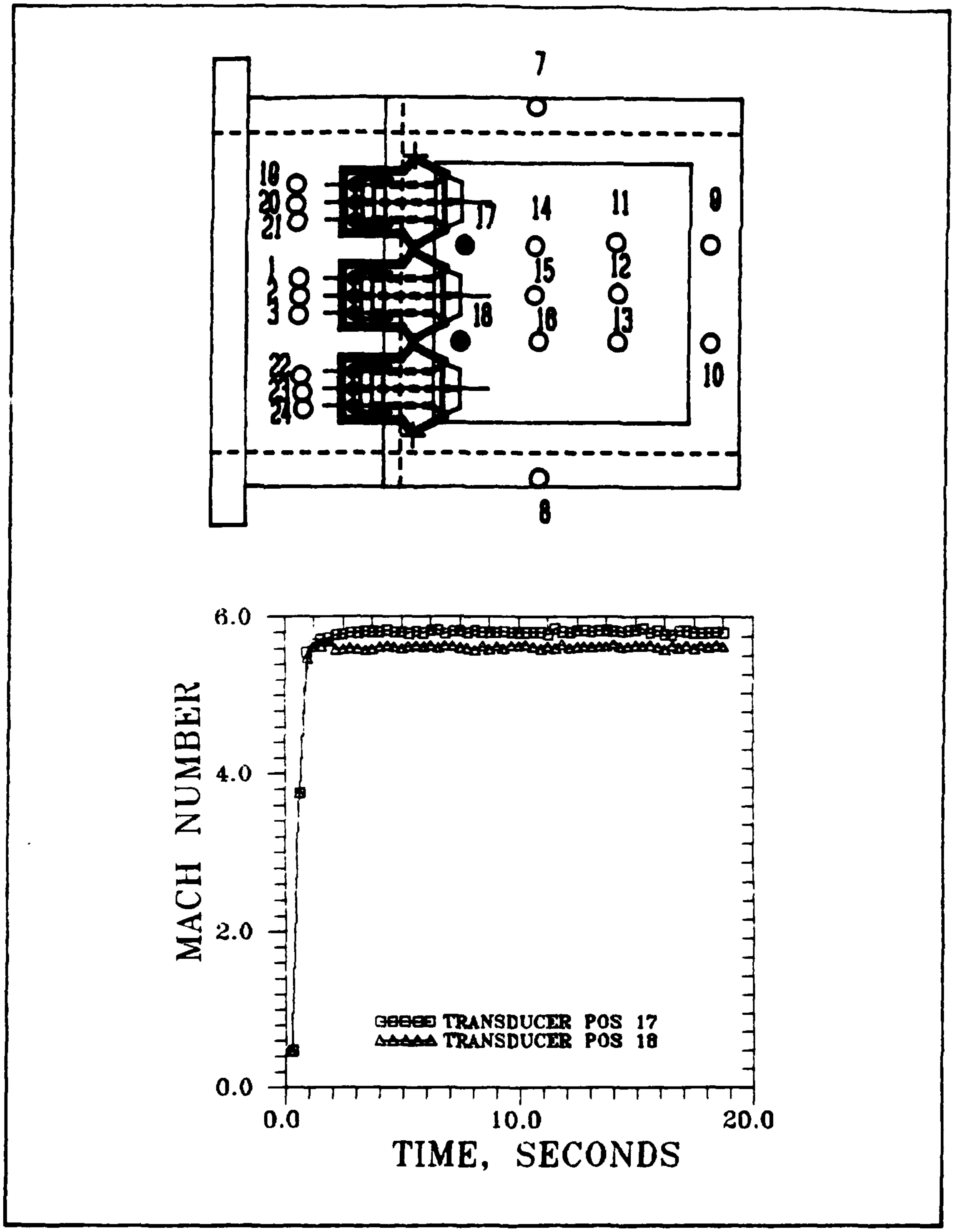

Figure 5.7. Nozzle Exit Mach Number M_e vs Time, Diffuser Throat 0.5625 inches

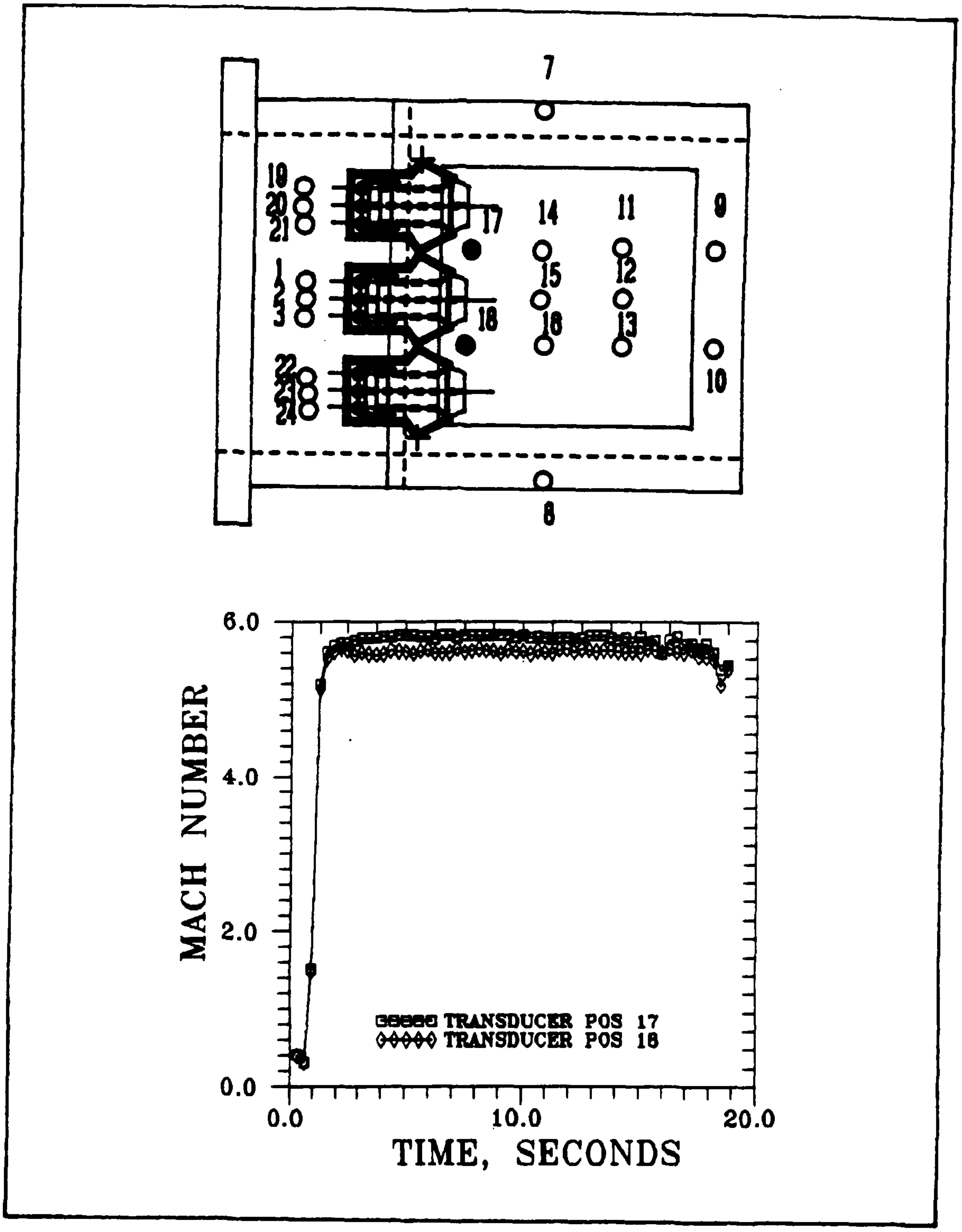

Figure 5.8. Nozzle Exit Mach Number M_e vs Time, Diffuser Throat 0.625 inches

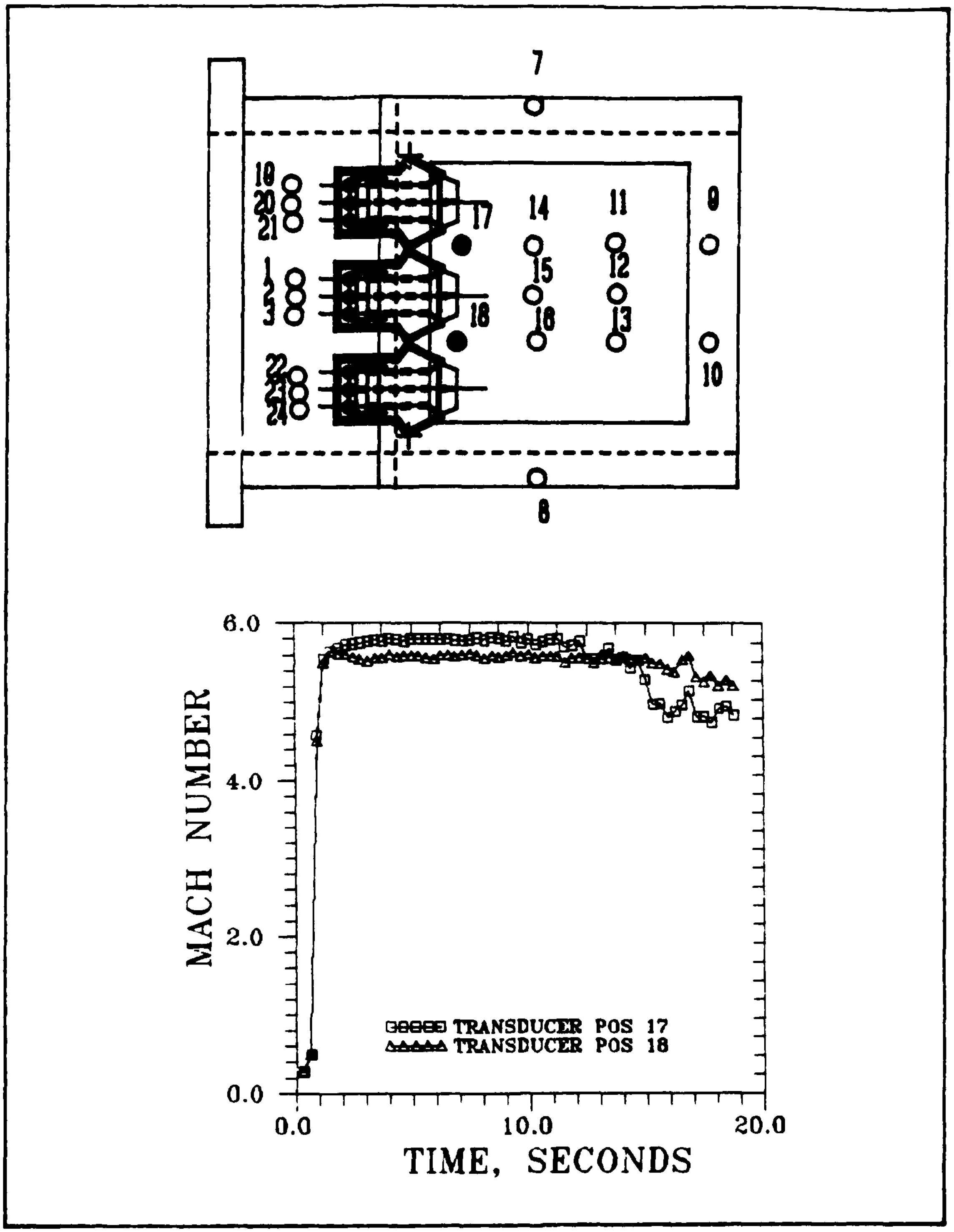

Figure 5.9. Nozzle Exit Mach Number M_e vs Time, Diffuser Throat 0.6875 inches

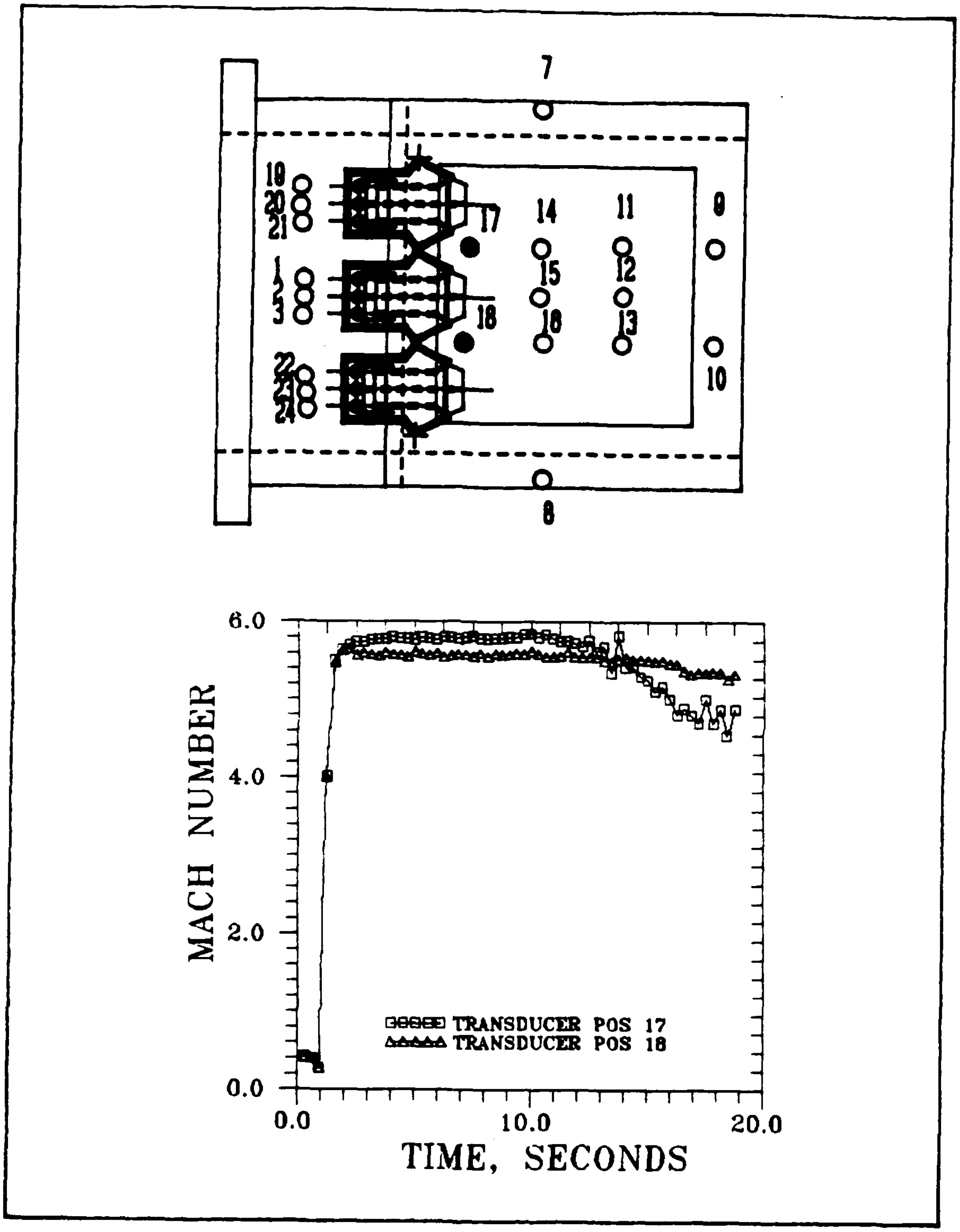

Figure 5.10. Nozzle Exit Mach Number M_e vs Time, Diffuser Throat 0.75 inches

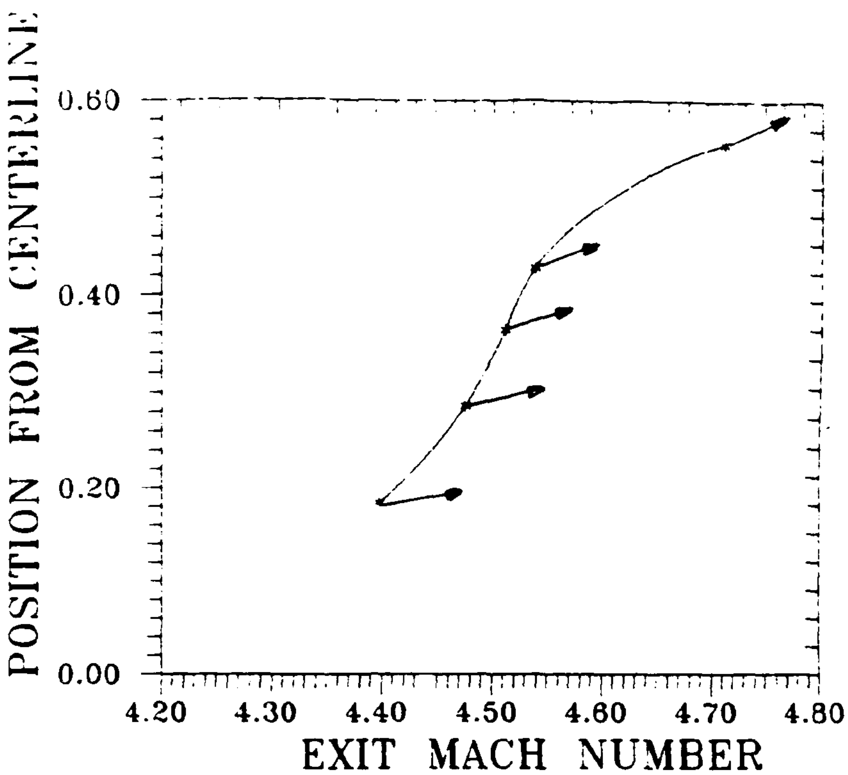

Figure 5.11. Variance of Mach Number and Flow Stream Angle at the Exit Plane of a Supersonic Nozzle

also increase causing the center of mass to shift towards the outside edge. Shifting the center of mass to the outside edge would also shift the average flow angle towards the outside edge. With that in mind, the Korst method was then used to determine the flow angle that fit the experimental pressure $\frac{p_2}{p_1}$. The average of the experimentally determined flow angles was calculated, 18.4 degrees, and was used as $\theta_{1a_{theoretical}}$. Using the experimentally calculated M_e and $\theta_{1a_{theoretical}}$, theoretical values for the pressures and the Mach numbers in the base region were calculated. The difference between the experimental pressure ratio and the theoretical pressure ratio were compared to indicate the validity of using the two-dimensional generalized Korst model. Table 5.1 summarizes the results of several calculations. Figure 5.12 shows the Korst theoretical curve and a data point calculated using the experimental data. Figure 5.13 demonstrates the effect of various flow stream angles as well as positions one of the experimentally derived points. From the results it would

Table 5.1. Base Region Results Comparison

Experimental		*Theoretical*		*Difference*
θ_{1a}	$\frac{p_2}{p_1}$	θ_{1a}	$\frac{p_2}{p_1}$	*(Percent)*
18.5	0.9012	18.4	0.8893	1.33
18.5	0.8995	18.4	0.8880	1.29
18.5	0.9051	18.4	0.8924	1.41
18.2	0.8622	18.4	0.8840	2.50

seem that the Korst method is an accurate model of the base region flow conditions. Further investigation into the selection of $\theta_{1a_{theoretical}}$ is necessary to confirm the accuracy of the results.

5.2.3 Cavity Flowfield Anaysis Static pressure taps and schlieren photographs were used to analyze the flow conditions in the cavity. Figures 5.3–5.6 show various flow conditiions at different diffuser throat settings. The first three diffuser throat settings produce underexpanded conditions at the exit of the nozzles and the flow expands outward to form the diamond pattern shown in the photographs. If the flow between transducer positions 17 and 14, shown in Figure 5.8, is considered to be shock free, then isentropic conditions can be applied. Using the stagnation pressure from upstream, the Mach number at postion 14 can be calculated. Figure 5.14 shows that the Mach number at postion 14 is initially larger than the Mach number at position 17, this indicates that normal isentropic expansion applies for the first few seconds of the run and then cavity conditions begin to detoriate producing a lower Mach number. Figures 5.15 and 5.16 show that static pressure increases long the nozzle centerline, with respect to time. Additionally, static pressure at position 11 was noted to jump above the static pressure at position 9, possibly indicating a strong shock system moving past position 11 and back towards the nozzle exit. Further investigation is necessary to understand why position 9 pressure readings are less than position 11. Pressure values in the figures where the

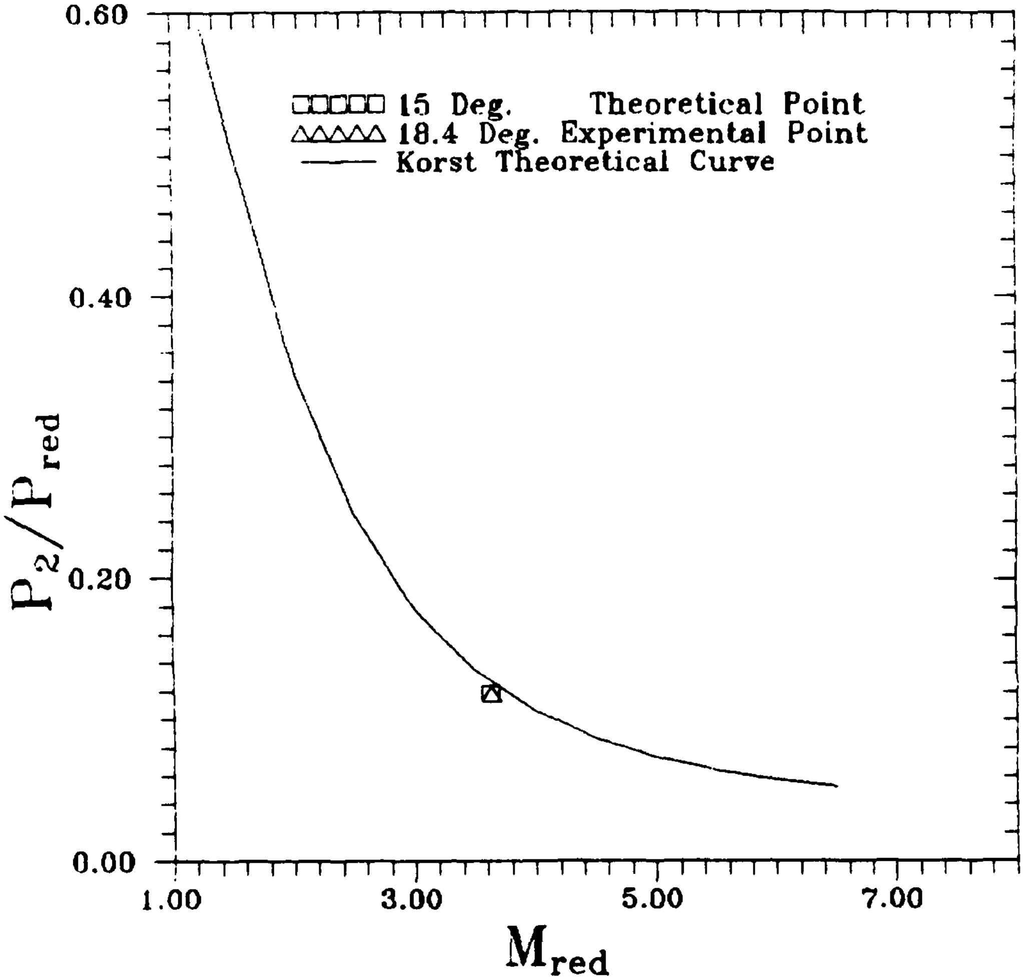

Figure 5.12. $\frac{P_2}{P_{red}}$ vs Reduced Approach Mach Number, Diffuser Throat Setting 0.625 inches

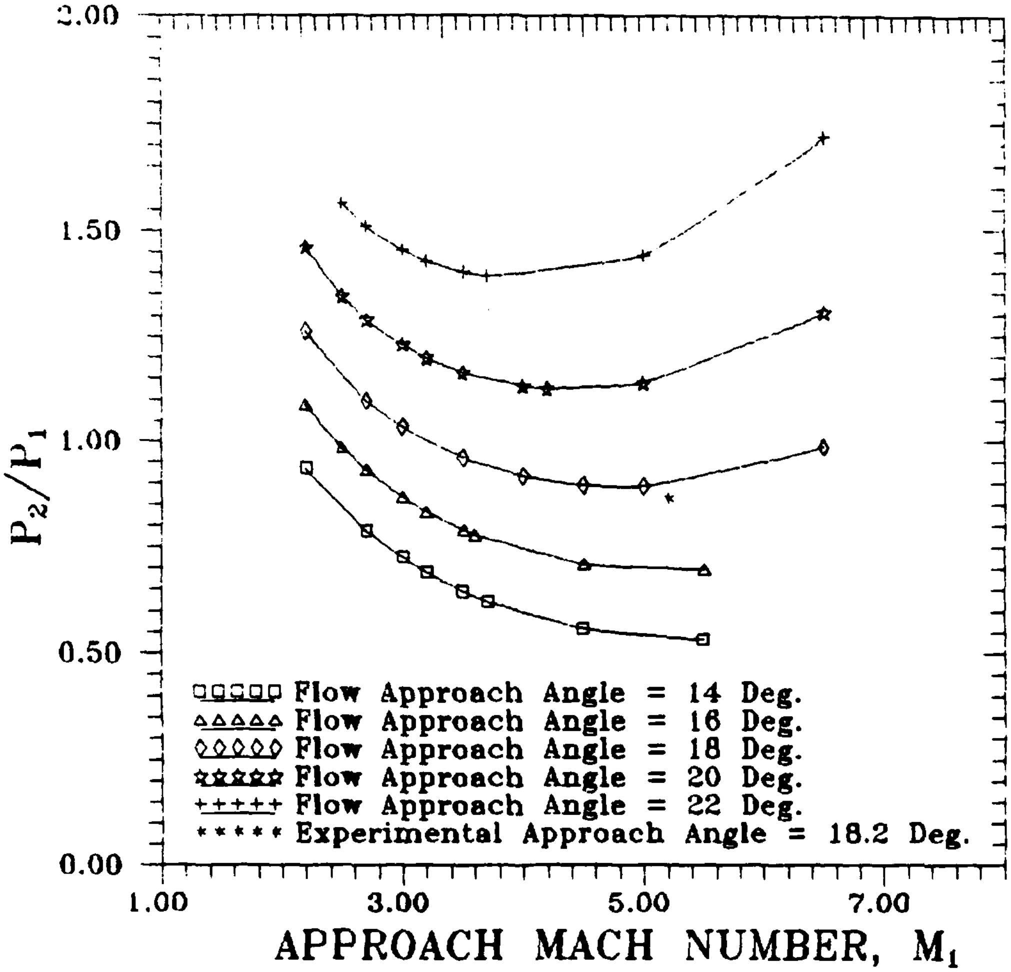

Figure 5.13. Effect of Approaching Flow Stream Angle in Korst Generalized Back Step Calculations, Diffuser Throat Setting 0.625 inches

phrase *smoothed data* is used indicates the pressure data has been artifically smoothed using an FFT program. Both Figure 5.15 and 5.16 indicate low, stable static pressure conditions close to the exit of the nozzle, but pressure becomes more unstable further out in the cavity section. Figures 5.17–5.20 show the base centerline static pressures, smoothed data, for all four diffuser settings. Trends in the smoothed data indicated the effects of the different diffuser settings. For example, Figure 5.18 shows that overall static pressure remains lower longer with the 0.625 setting than with the other three diffuser settings. However, analyzing the unsmoothed data points also provides some insight into the dynamics of the flow stream. Figures 5.21–5.32 show both the actual and the smoothed datapoints for two diffuser settings, 0.625 and 0.5625 and clearly indicate the fluxuating conditions in the cavity. A comparison of the figures indicate that the 0.625 diffuser setting provides stable cavity conditions for the longest time period.

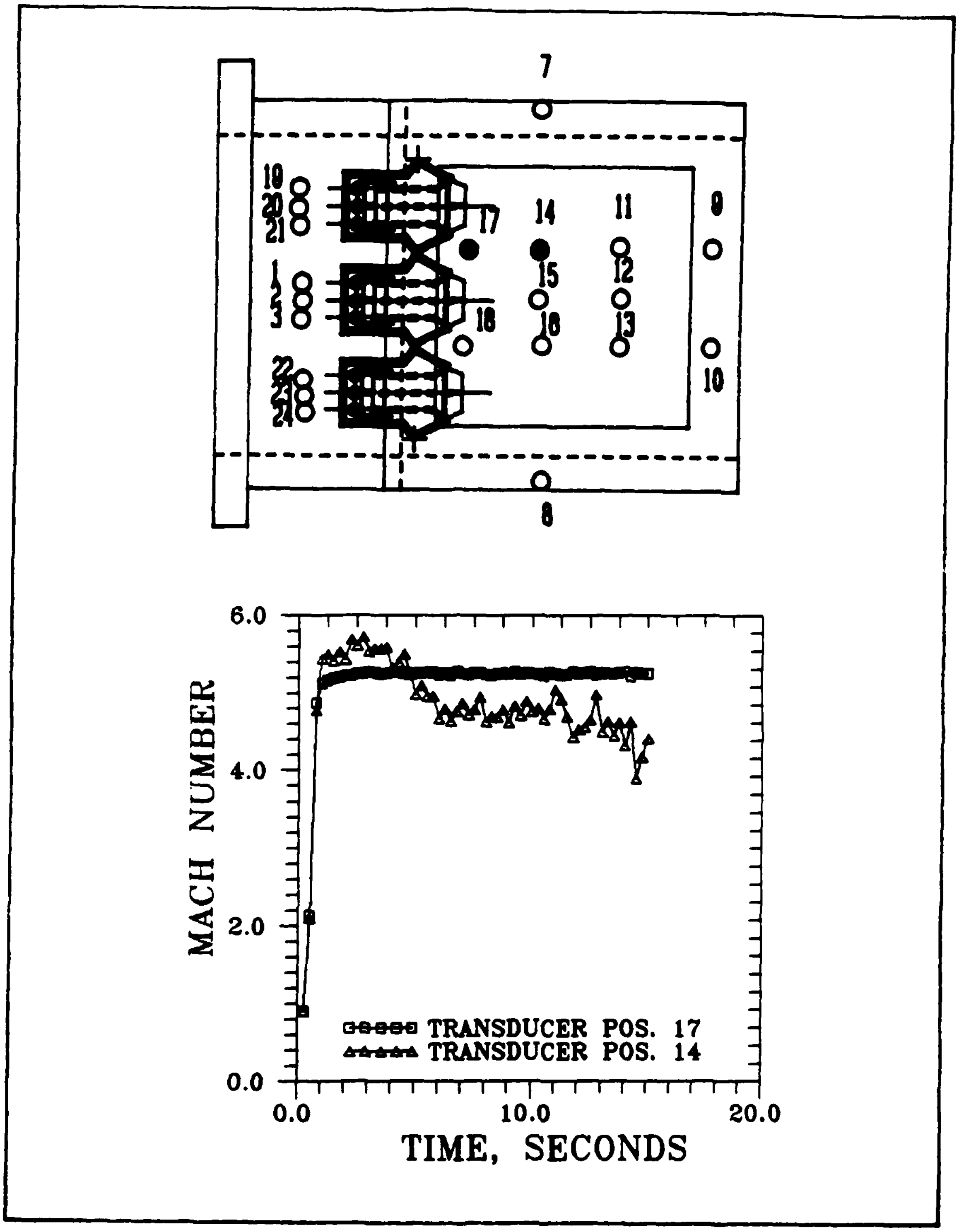

Figure 5.14. Nozzle Centerline Mach Number vs Time, Diffuser Throat Area Ratio 0.625

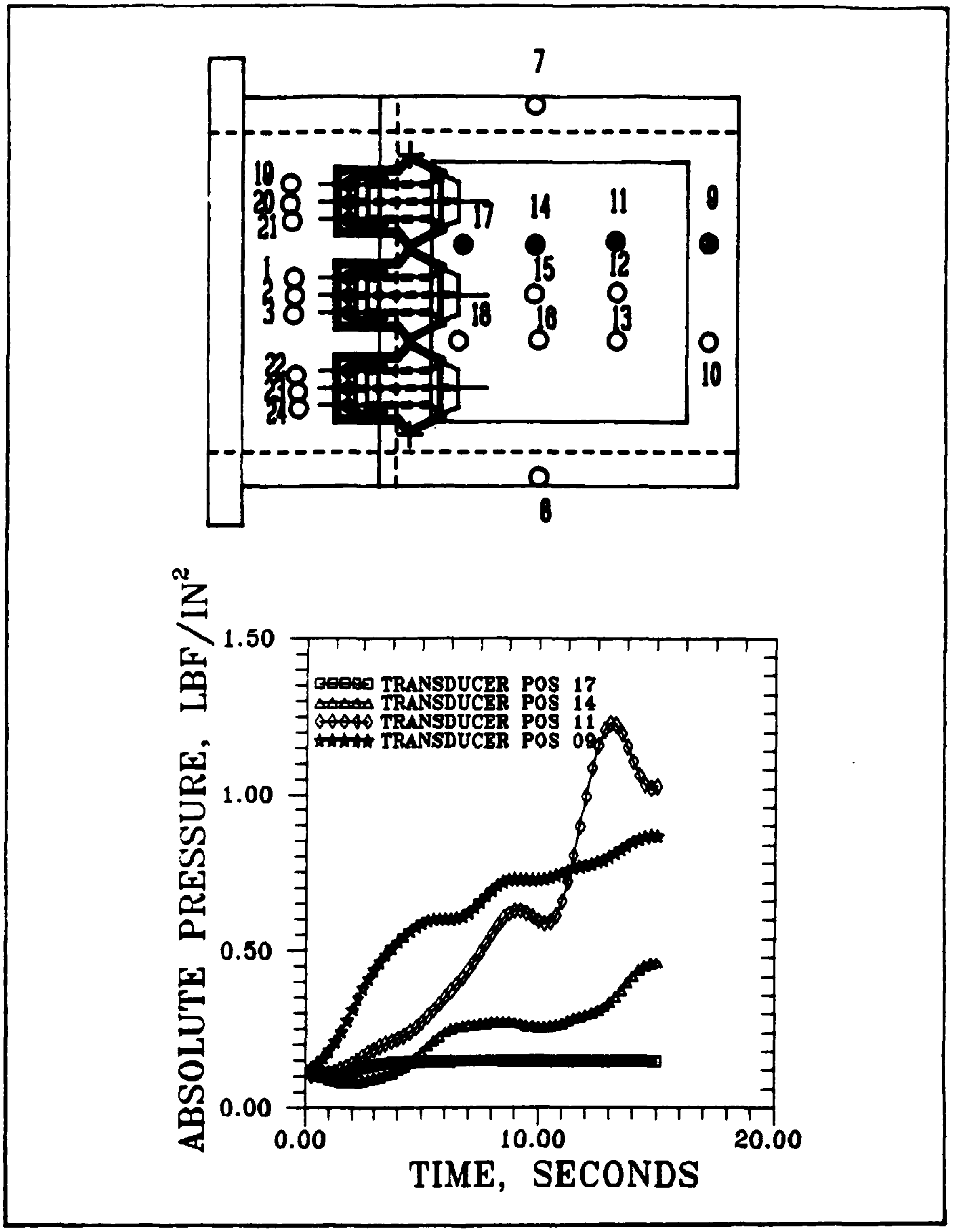

Figure 5.15. Nozzle Centerline Static Pressure Measurements vs Time, Diffuser Throat Area Ratio of 0.625, Smoothed Data

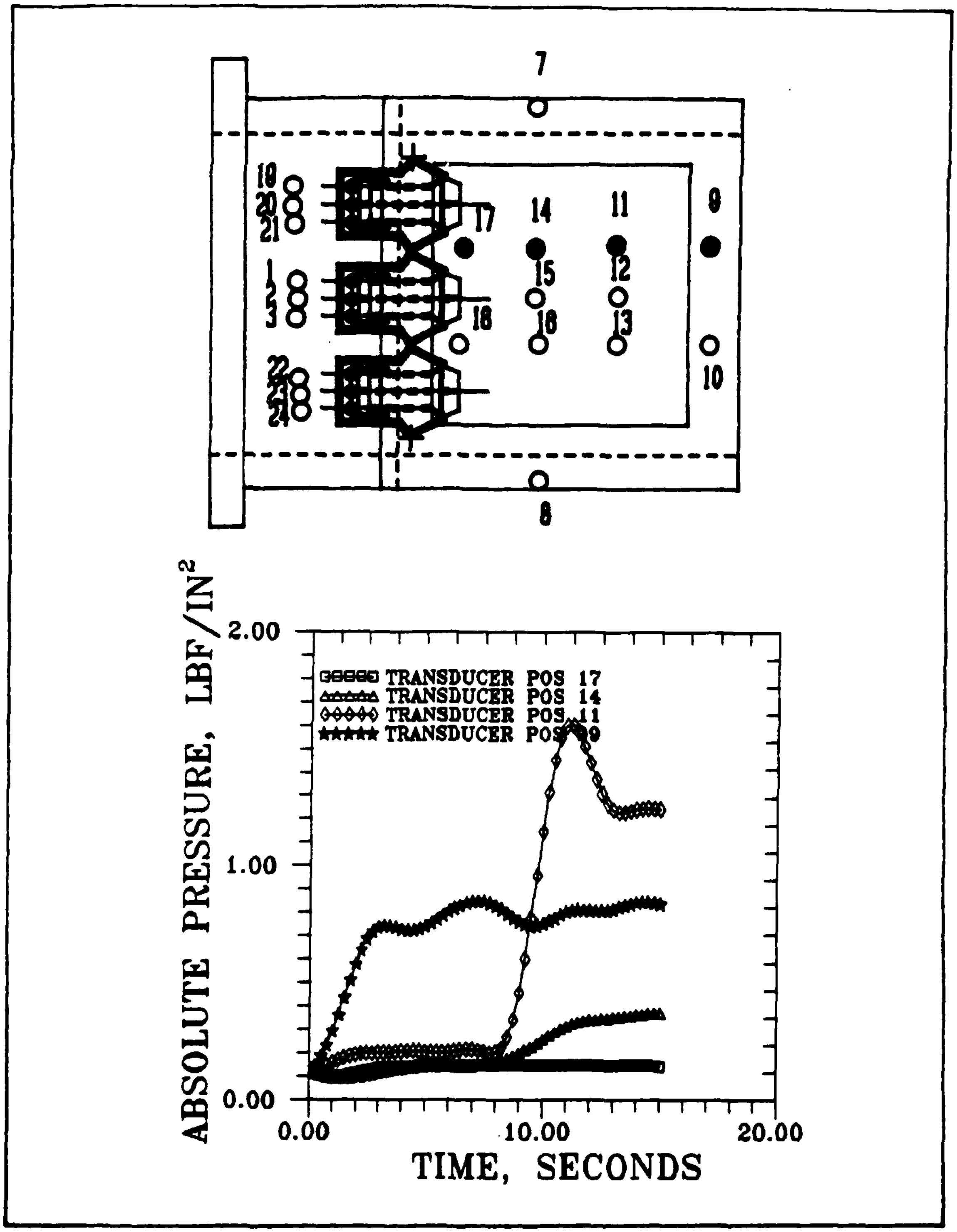

Figure 5.16. Nozzle Centerline Static Pressure Measurements vs Time, Diffuser Throat Area Ratio of 0.5625, Smoothed Data

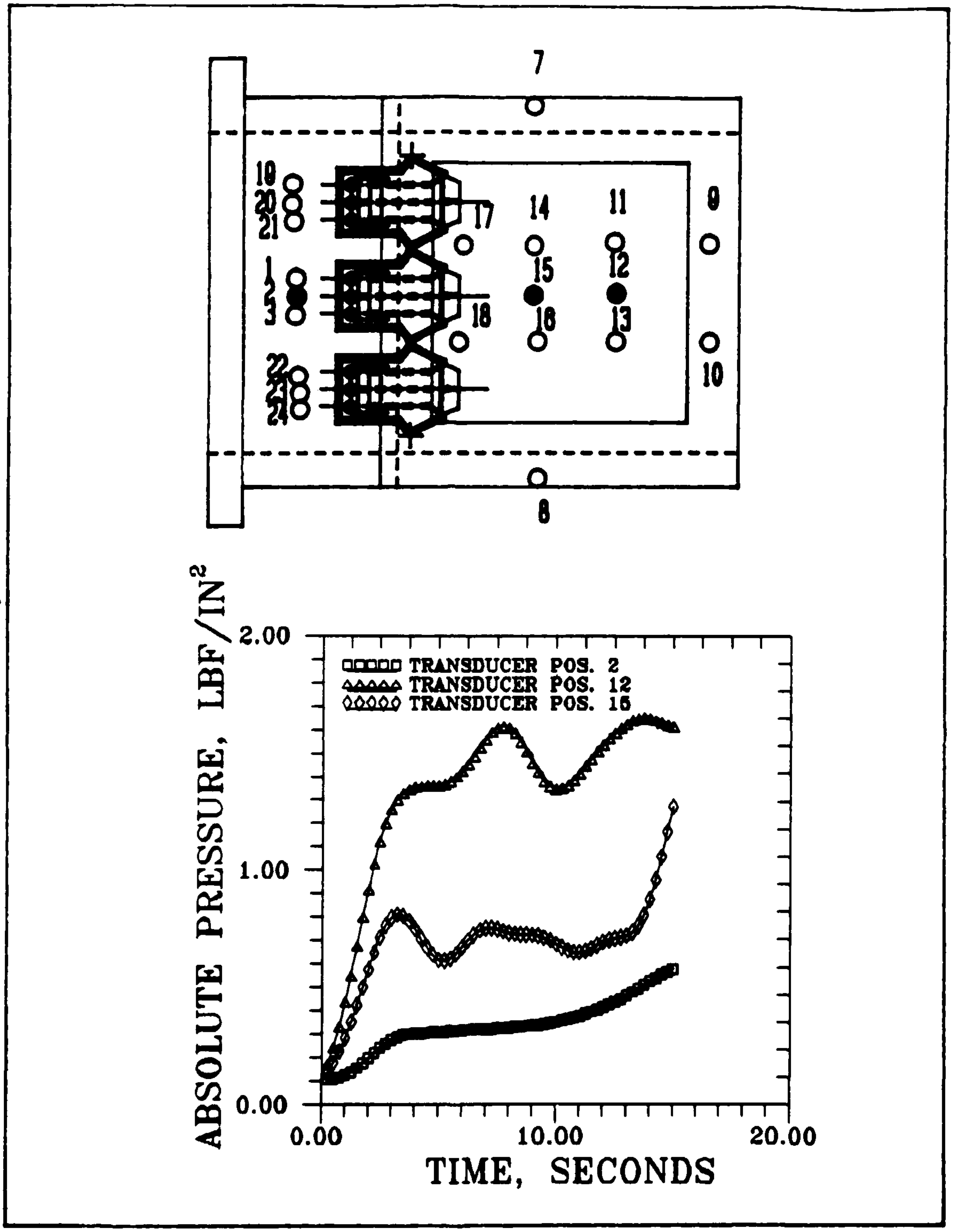

Figure 5.17. Base Centerline Static Pressure Measurements vs Time, Diffuser Throat Area Ratio of 0.5625, Smoothed Data

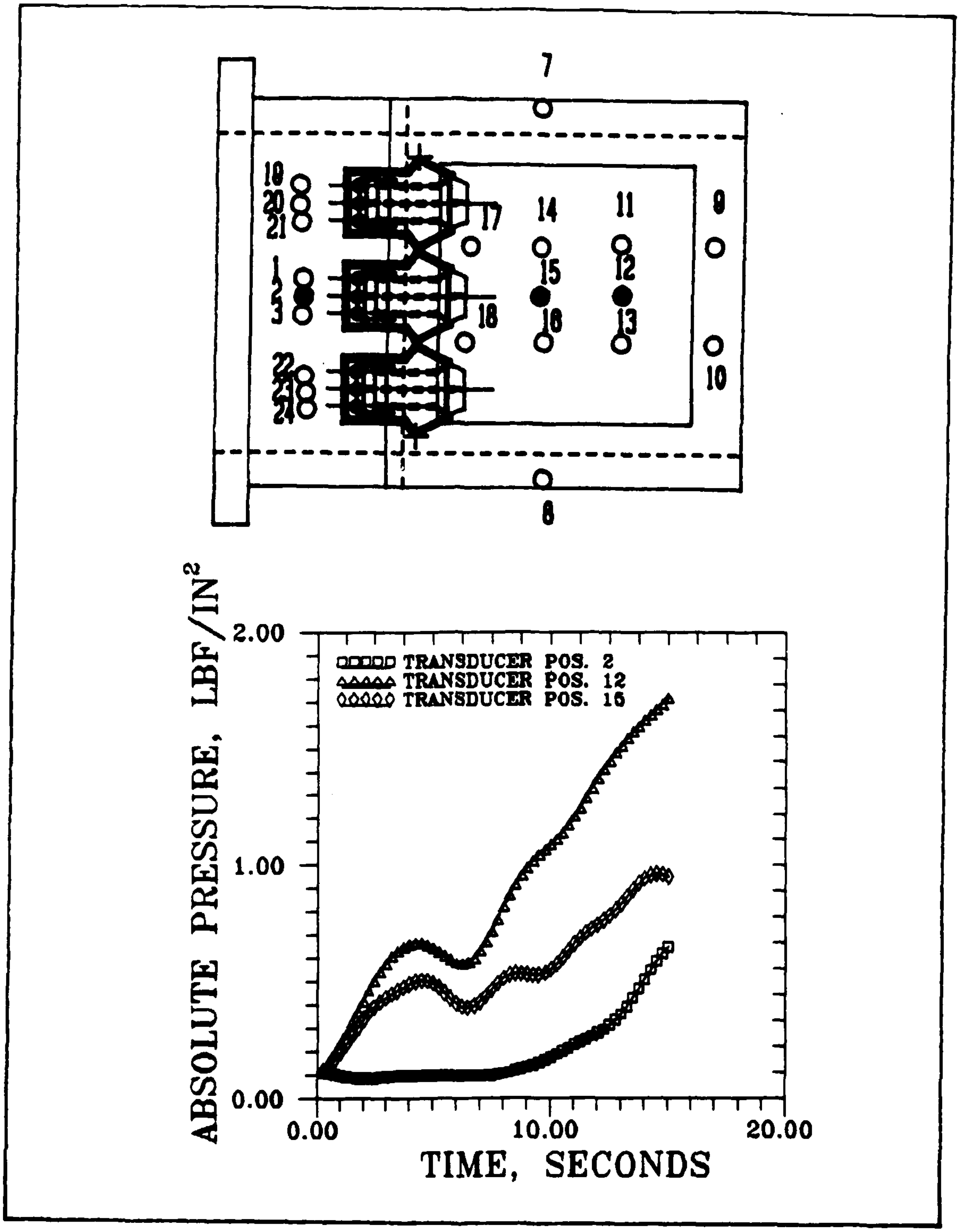

Figure 5.18. Base Centerline Static Pressure Measurements vs Time, Diffuser Throat Area Ratio of 0.625, Smoothed Data

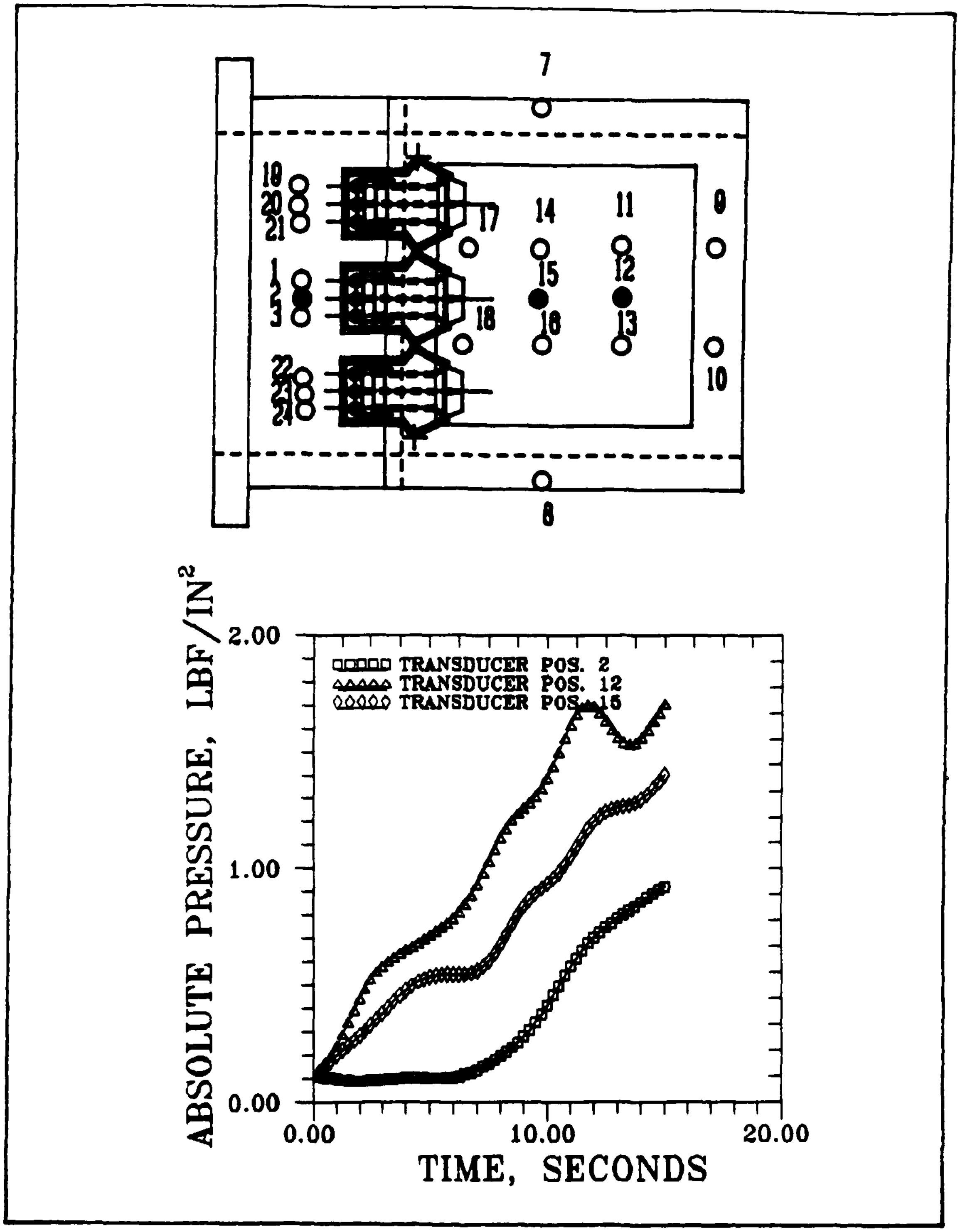

Figure 5.19. Base Centerline Static Pressure Measurements vs Time, Diffuser Throat Area Ratio of 0.6875, Smoothed Data

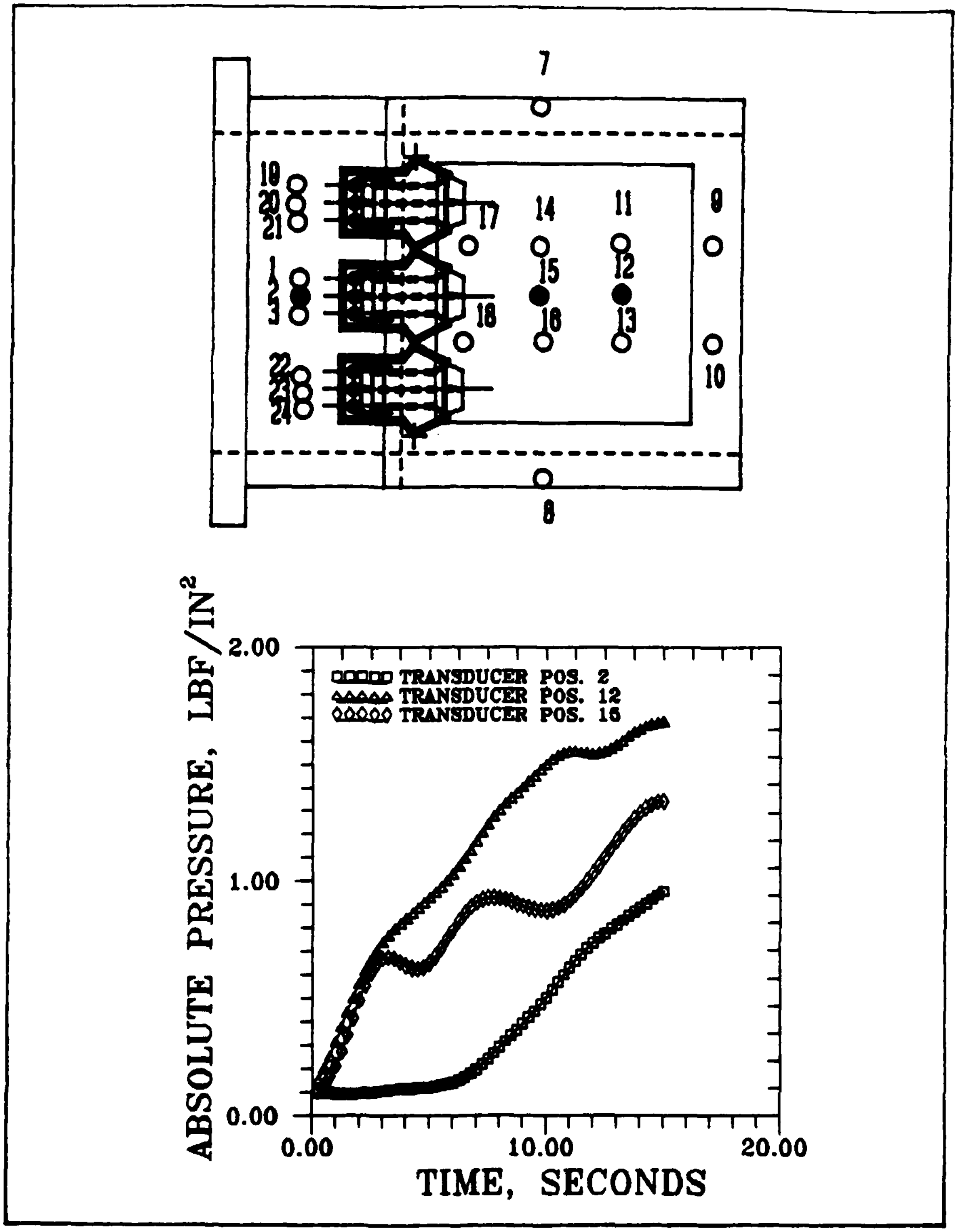

Figure 5.20. Base Centerline Static Pressure Measurements vs Time, Diffuser Throat Area Ratio of 0.75, Smoothed Data

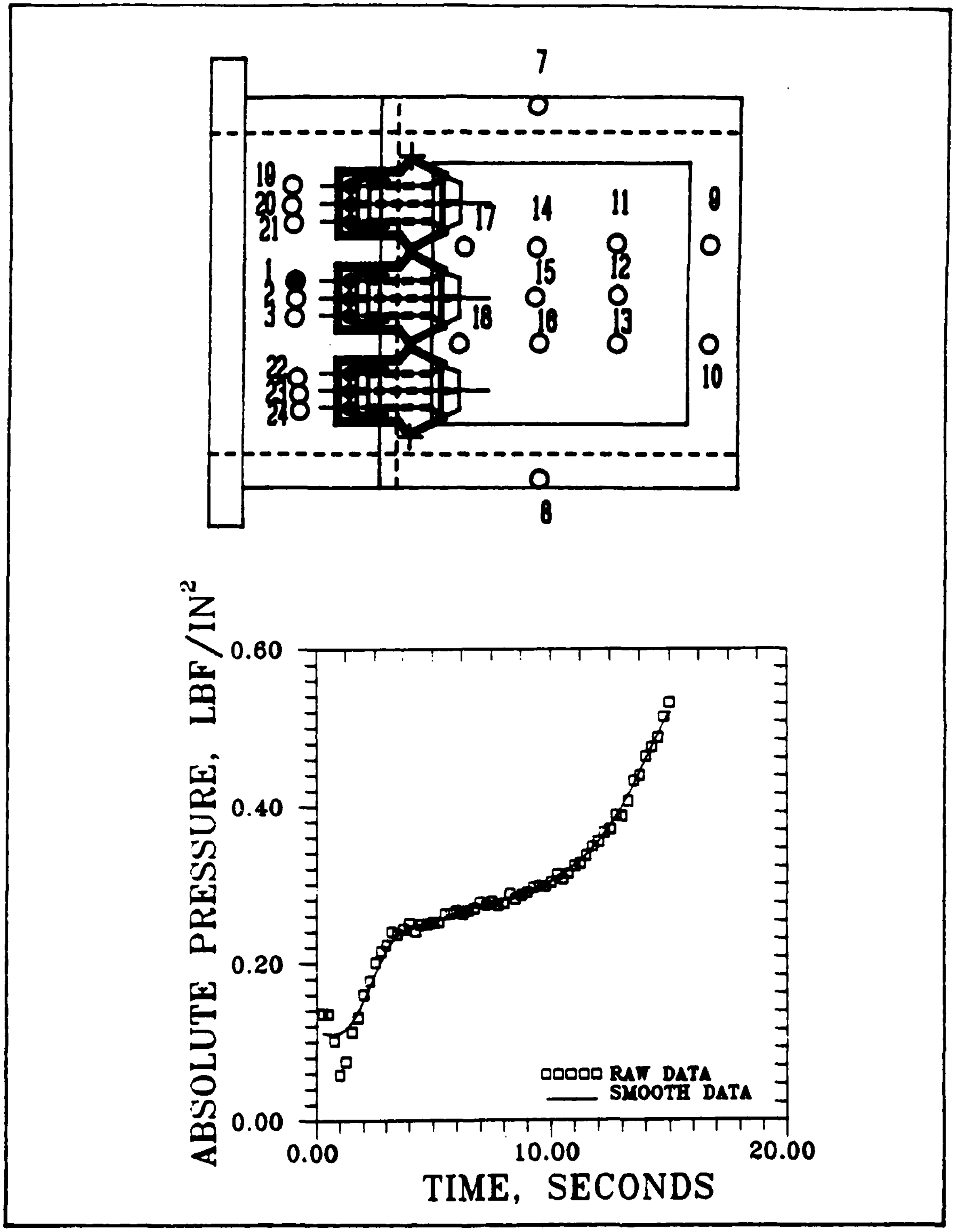

Figure 5.21. Static Pressure vs Time, Diffuser Throat Area Ratio of 0.5625, Transducer Position #1

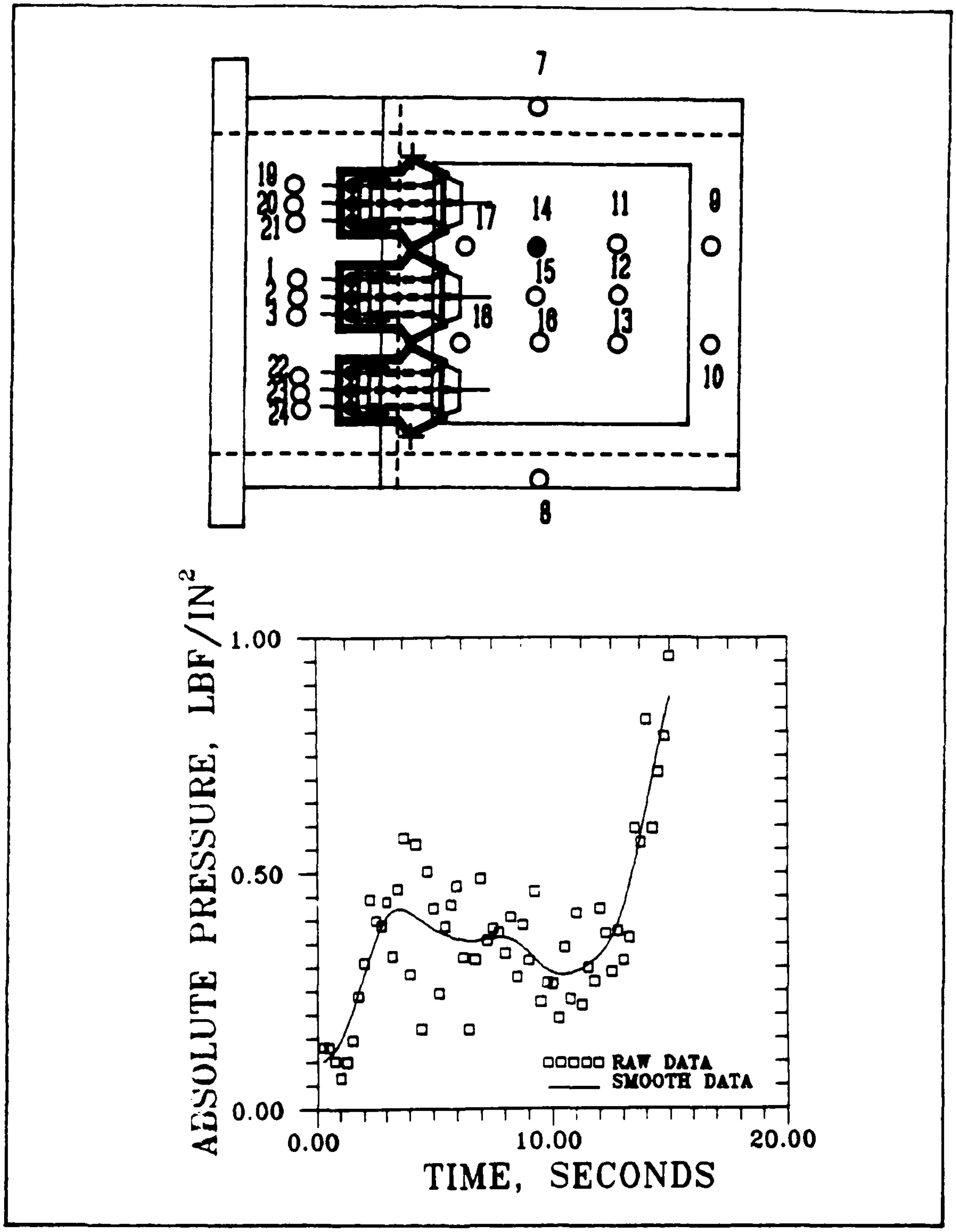

Figure 5.22. Static Pressure vs Time, Diffuser Throat Area Ratio of 0.5625, Transducer Position #14

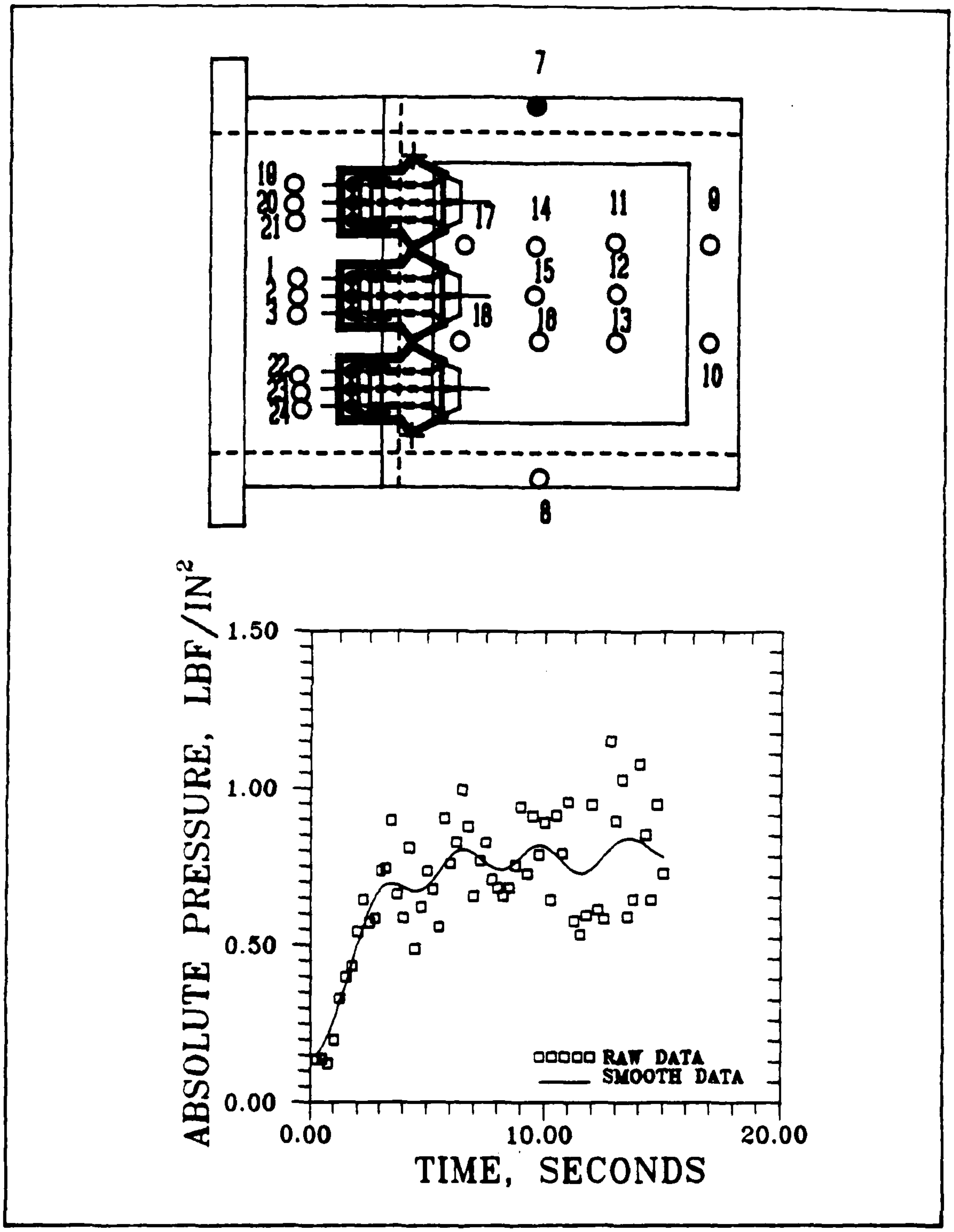

Figure 5.23. Static Pressure vs Time, Diffuser Throat Area Ratio of 0.5625, Transducer Position #7

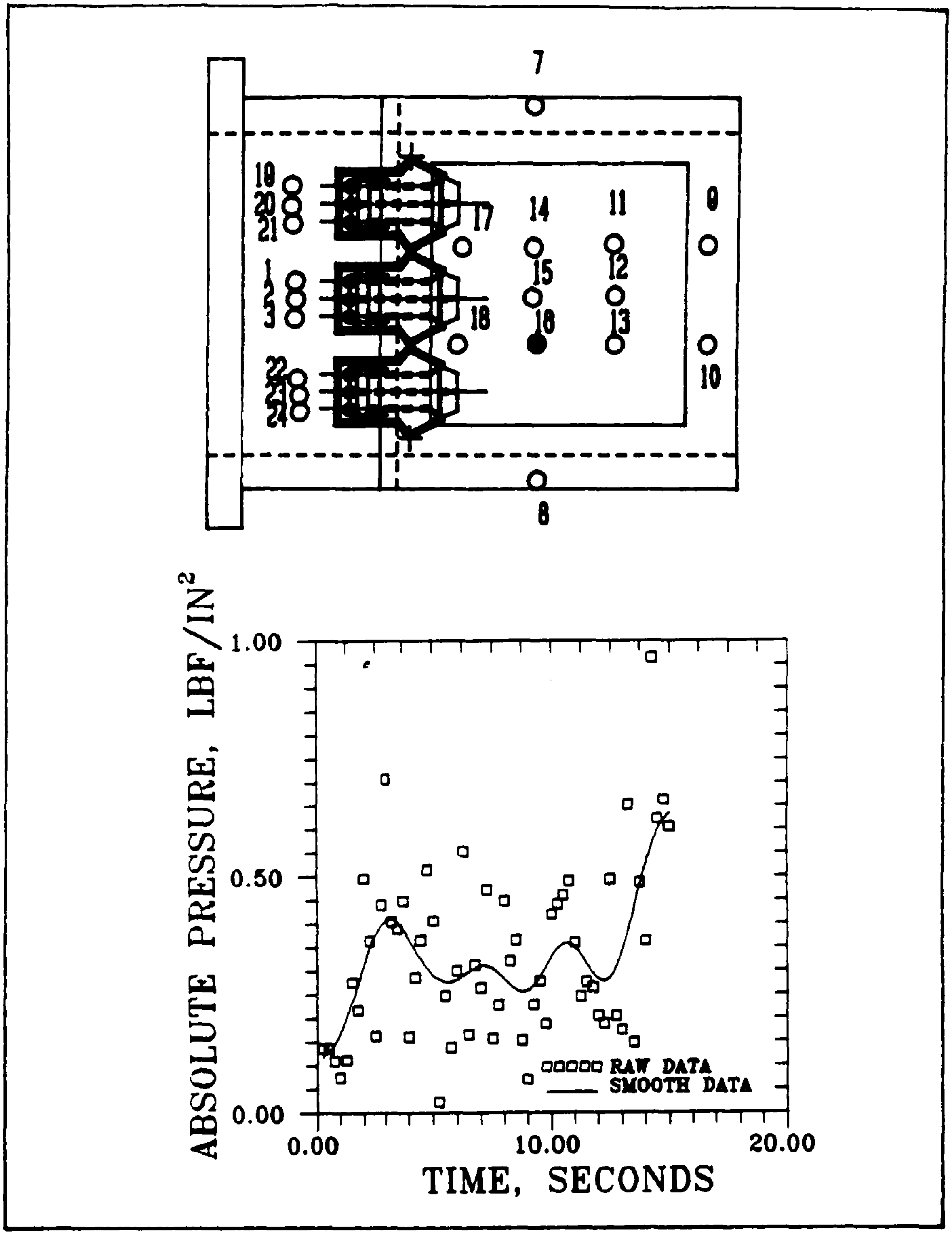

Figure 5.24. Static Pressure vs Time, Diffuser Throat Area Ratio of 0.5625, Transducer Position #16

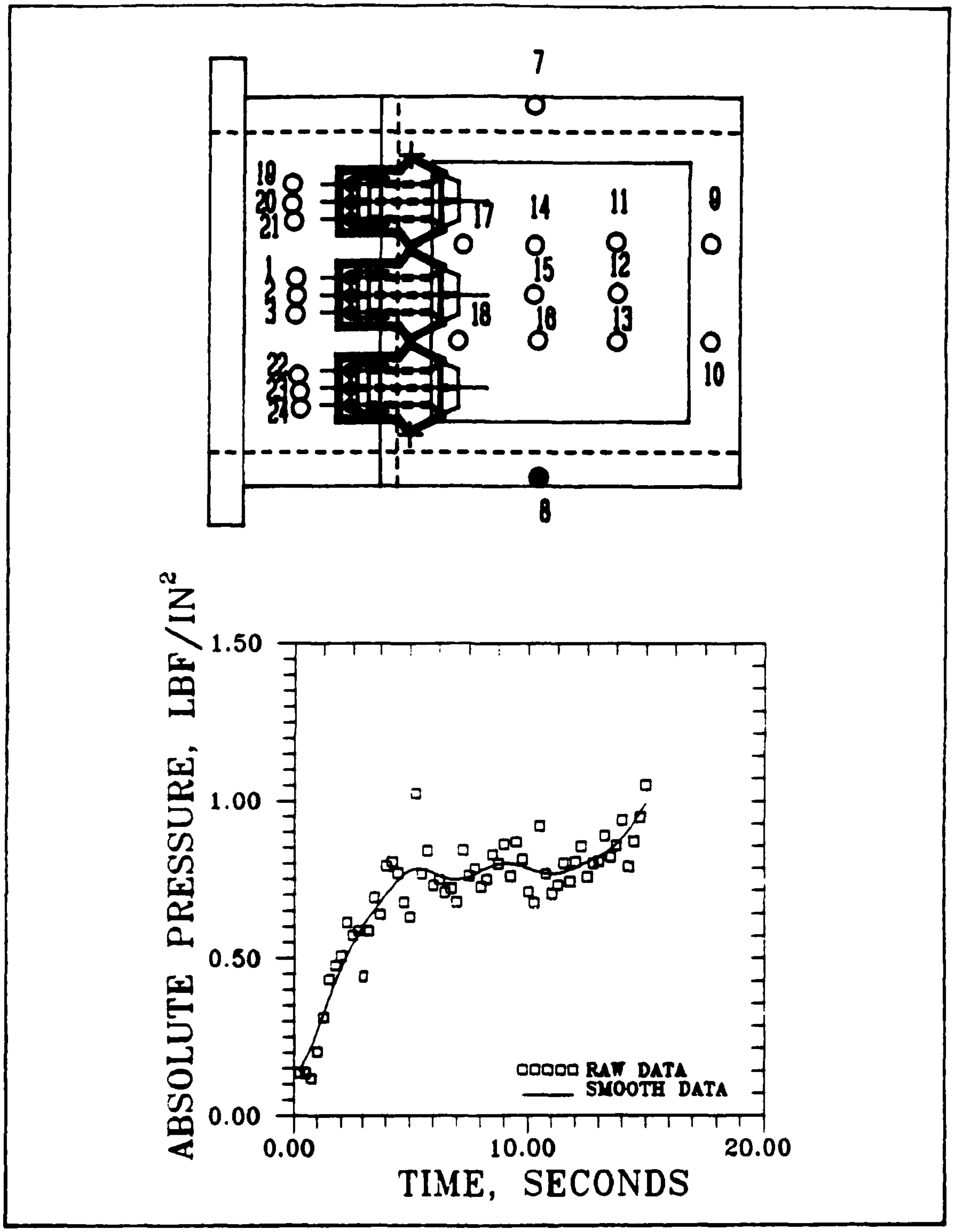

Figure 5.25. Static Pressure vs Time, Diffuser Throat Area Ratio of 0.5625, Transducer Position #8

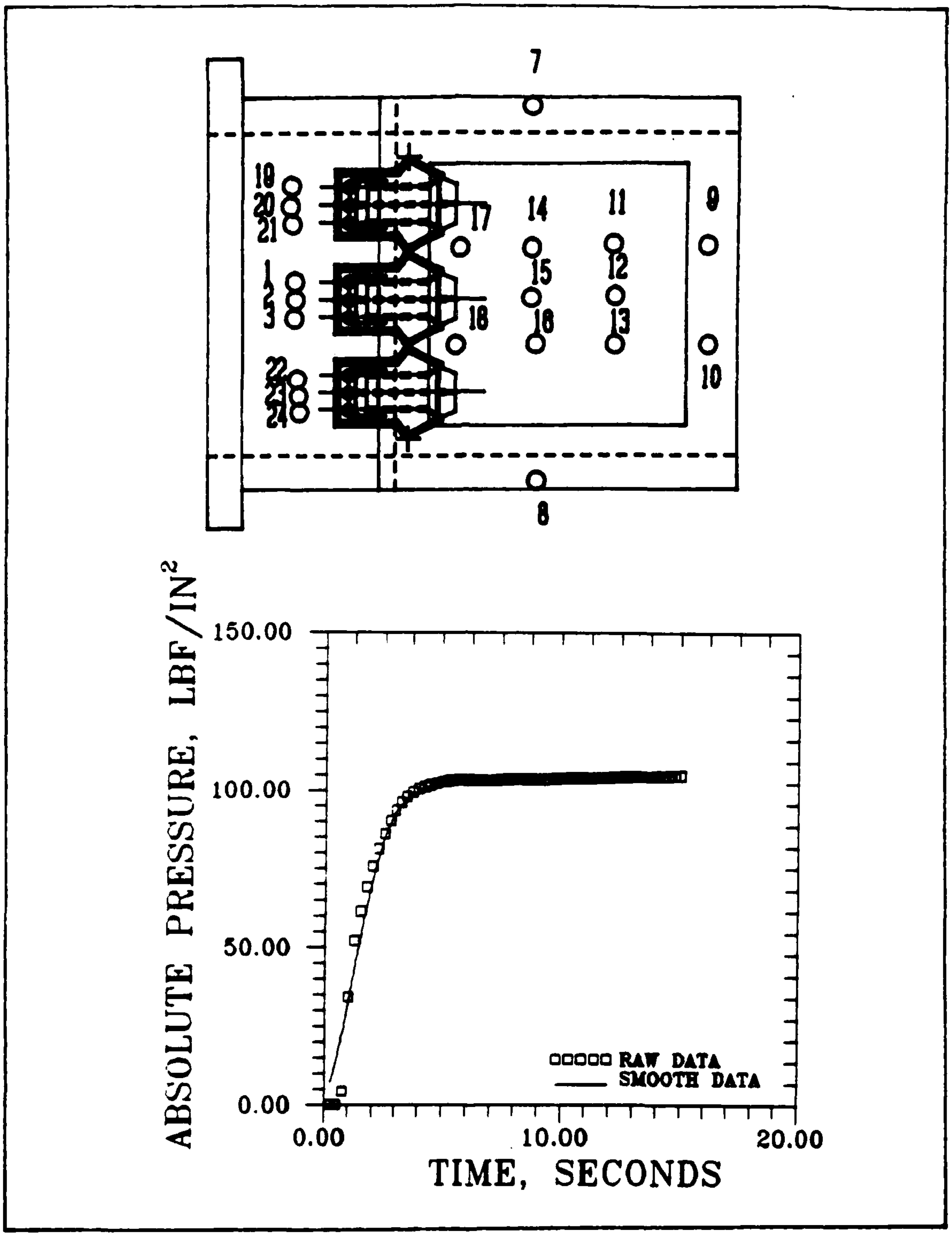

Figure 5.26. Static Pressure vs Time, Diffuser Throat Area Ratio of 0.5625, Transducer Position #6

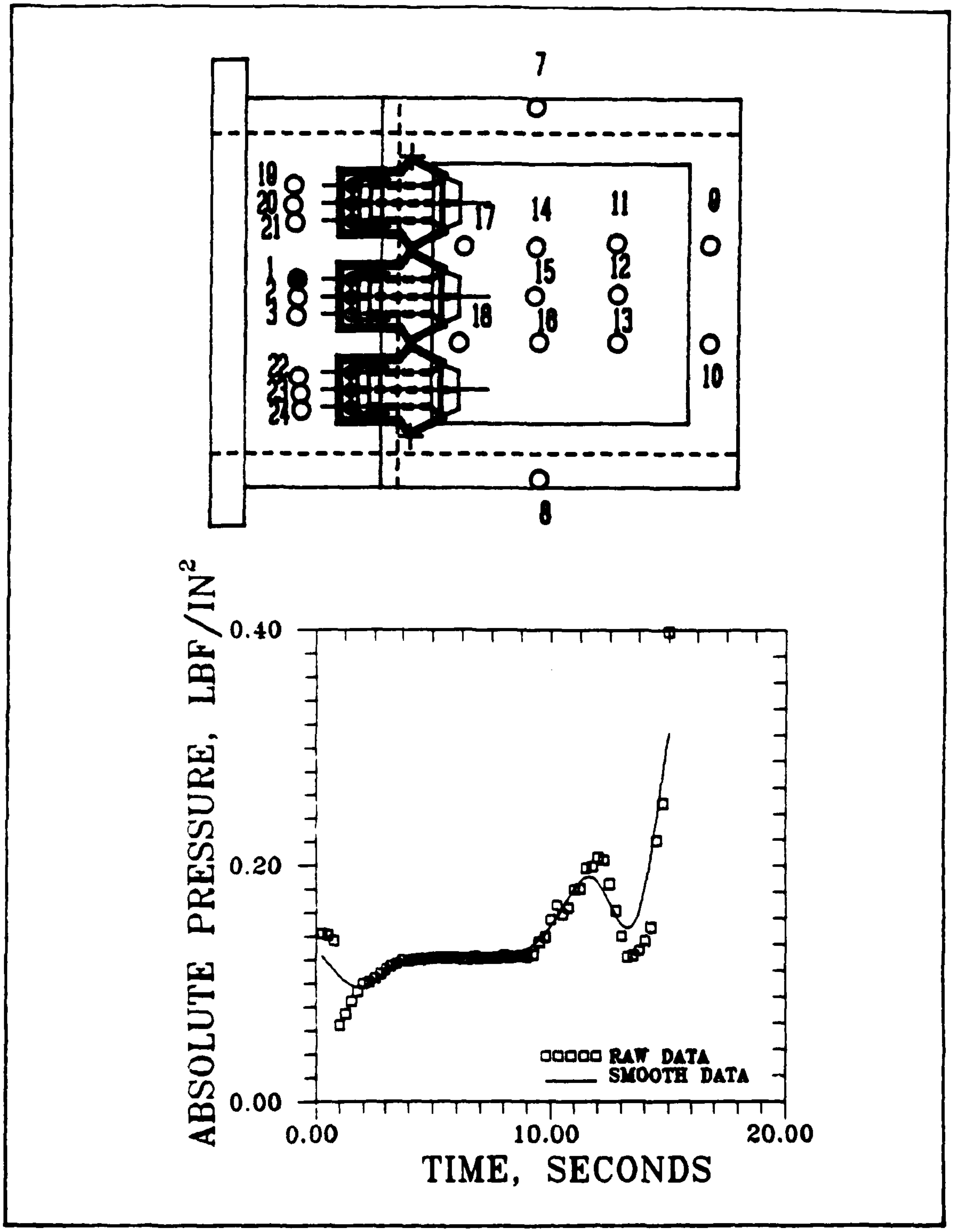

Figure 5.27. Static Pressure vs Time, Diffuser Throat Area Ratio of 0.625, Transducer Position #1

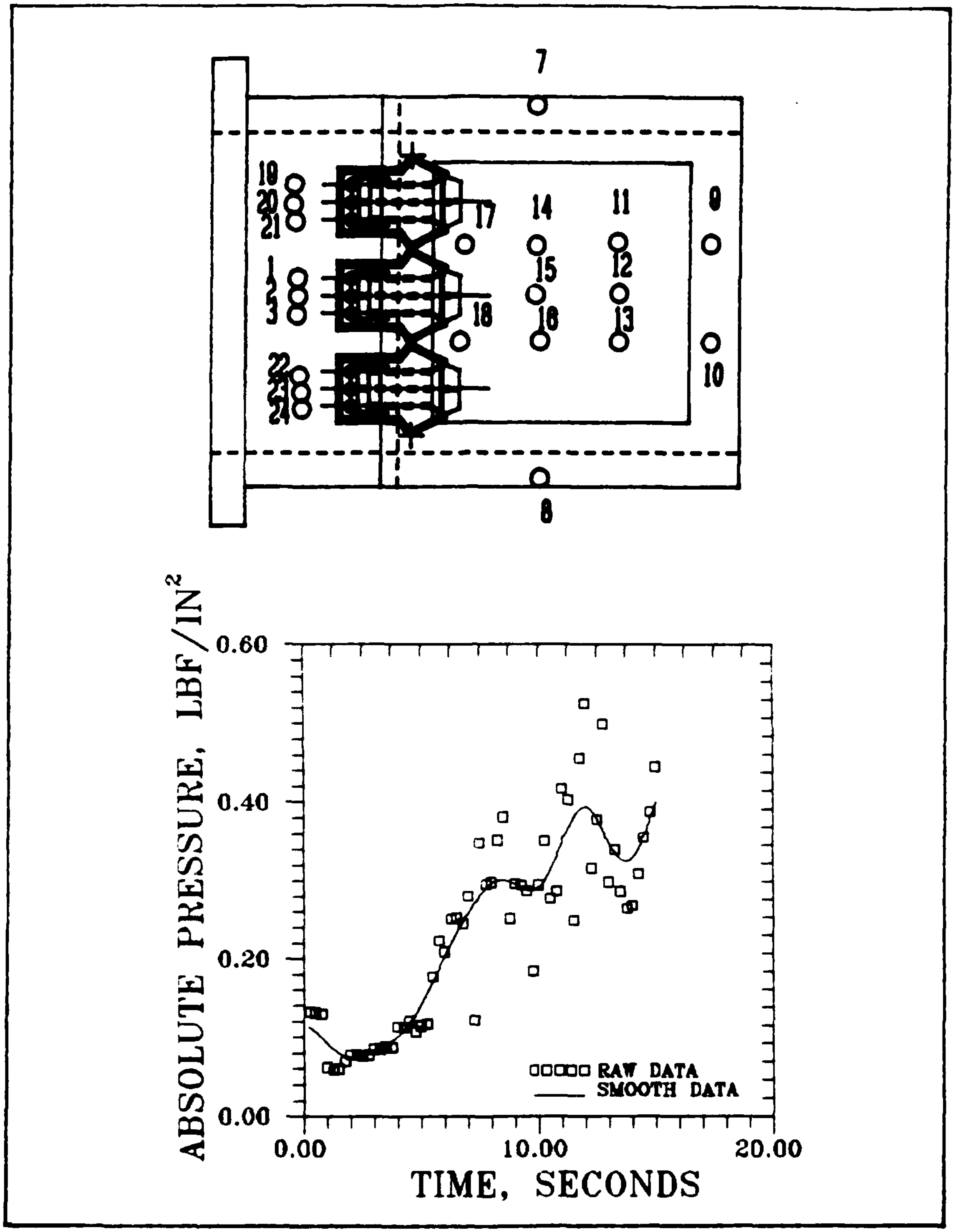

Figure 5.28. Static Pressure vs Time, Diffuser Throat Area Ratio of 0.625, Transducer Position #14

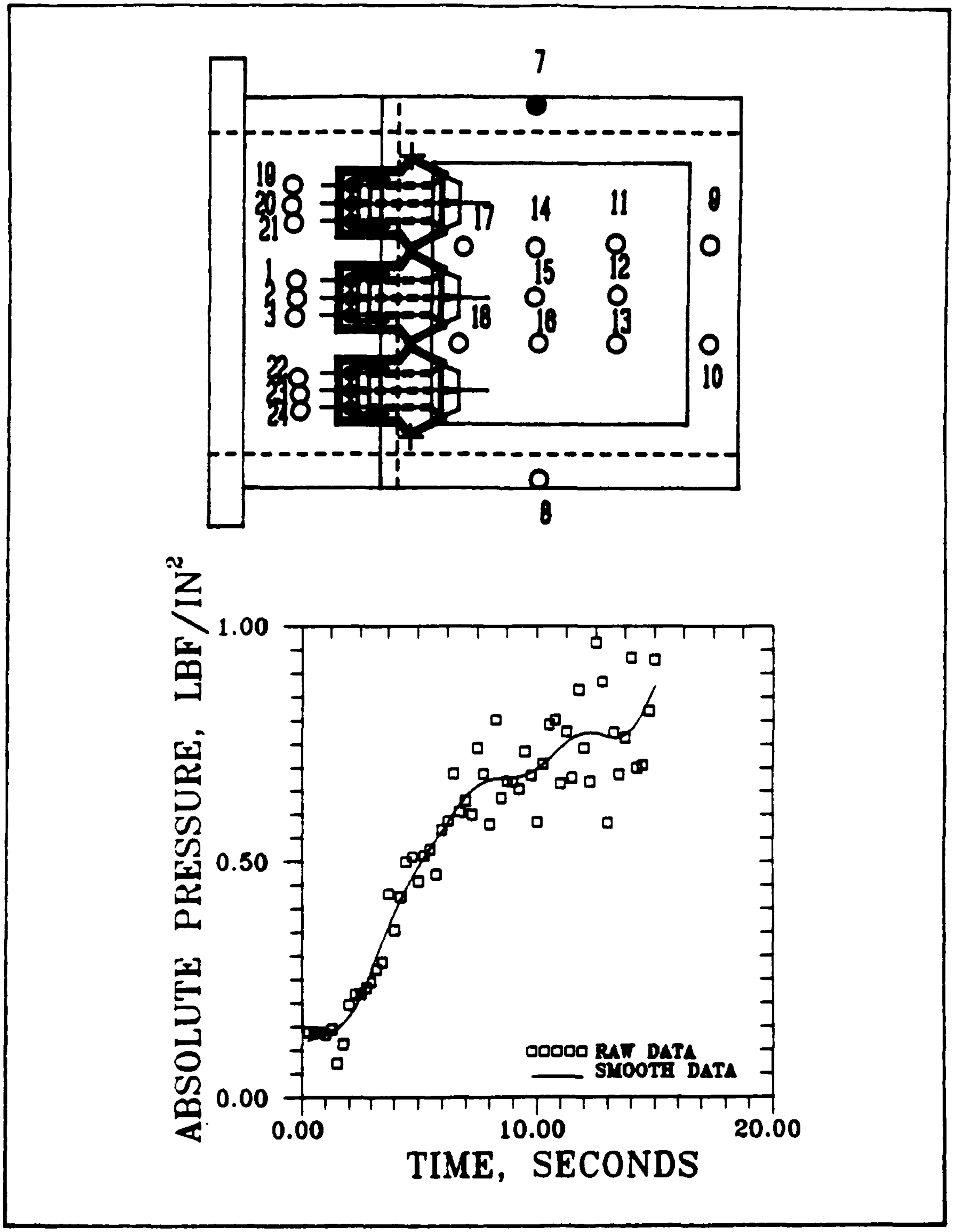

Figure 5.29. Static Pressure vs Time, Diffuser Throat Area Ratio of 0.625, Transducer Position #7

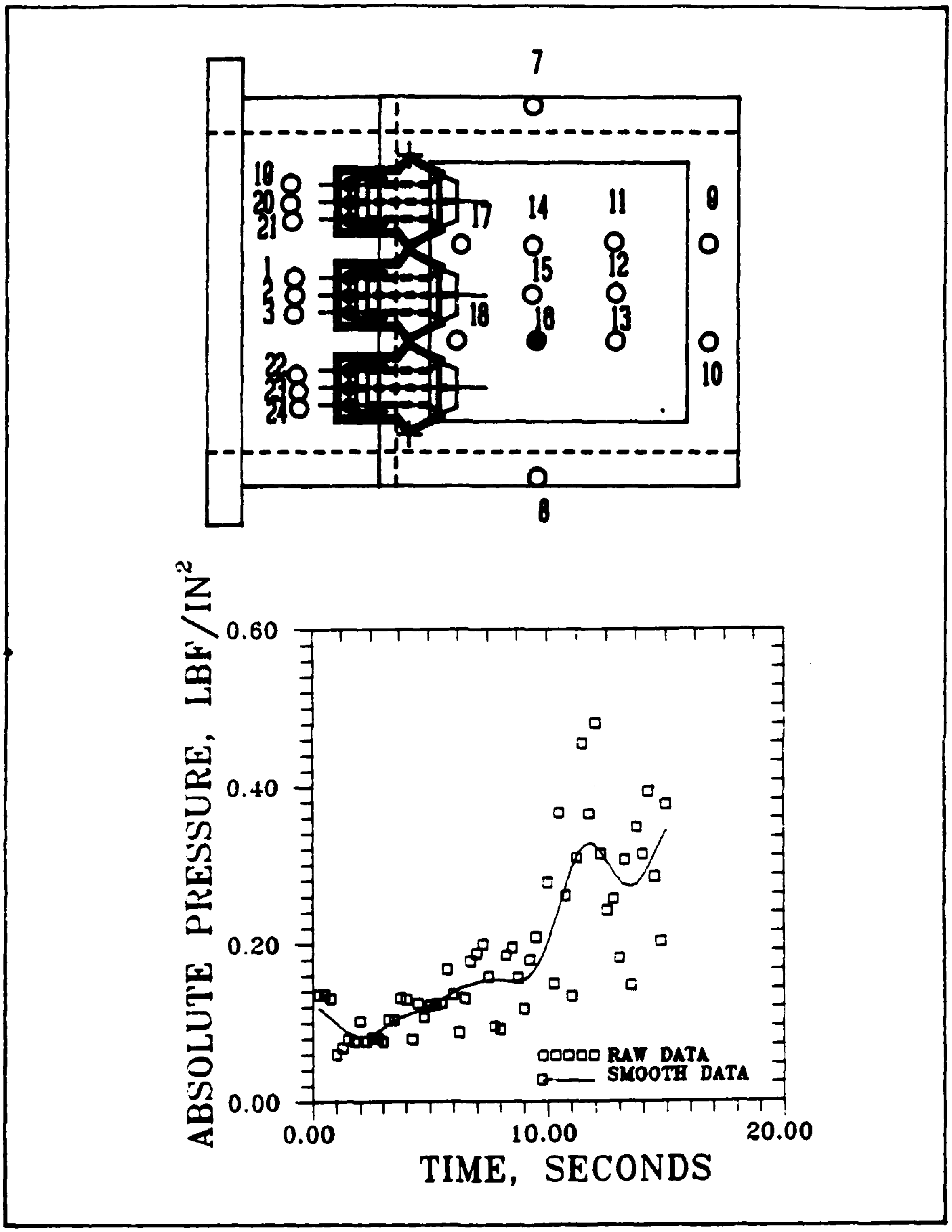

Figure 5.30. Static Pressure vs Time, Diffuser Throat Area Ratio of 0.625, Transducer Position #16

Flow conditions in the cavity regions are very complex. A more thorough investigation into the individual flow charateristics is necessary before the flow patterns can be fully understood. Additional information such as stagnation pressure in the cavity and additional static pressure ports might improve the mapping of the flowfield. Trends in the base centerline pressures can also help analyze the wake closure and wake opening. Comparision of the cavity static pressures with the vacuum static pressure, transducer position 5, indicates that the base centerline wake regions start to open up when the centerline to vacuum static pressure ratio $\frac{p_s}{p_{svacuum}}$ is higher than 0.20. Further investigation into the possible application of the Korst escape criterion to the wake might help describe the flow. Finally, interferometer photographs might improve visual inspection of the low density flowfield.

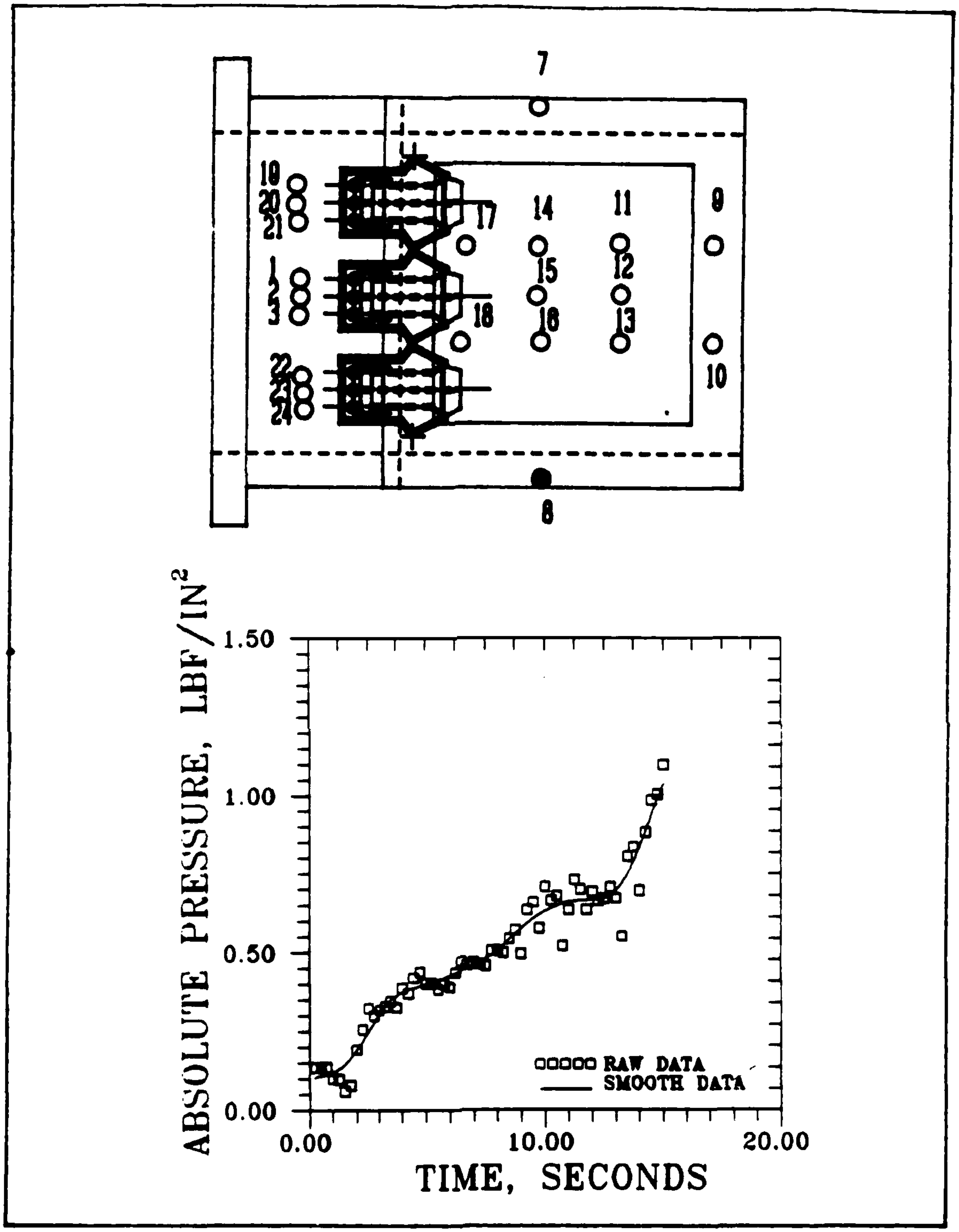

Figure 5.31. Static Pressure vs Time, Diffuser Throat Area Ratio of 0.625, Transducer Position #8

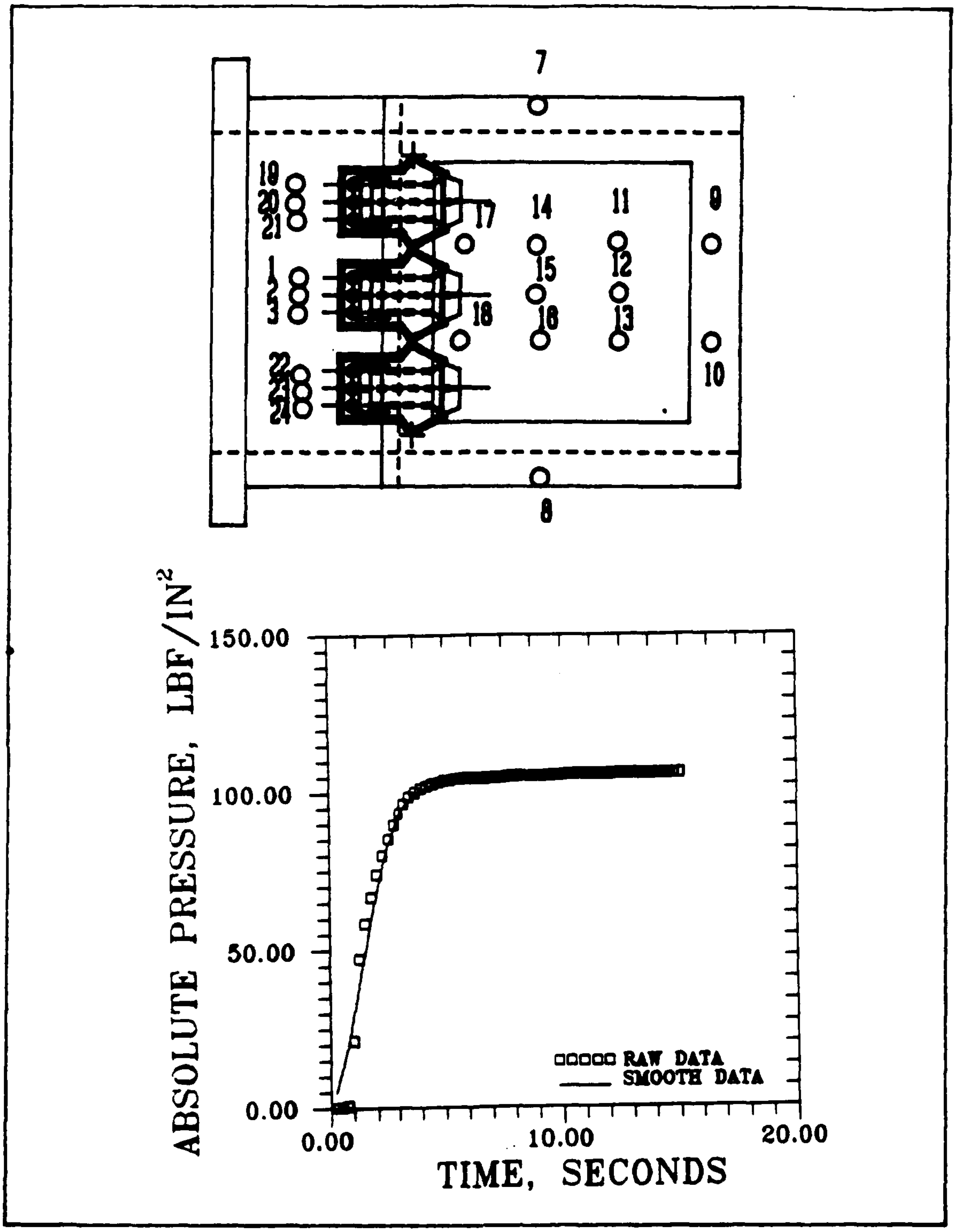

Figure 5.32. Static Pressure vs Time, Diffuser Throat Area Ratio of 0.625, Transducer Position #6

VI. Conclusions

An experimental investigation of the flowfield in a simulated chemical laser cavity was accomplished. The time history of static pressure at various locations in the cavity and schlieren photographs of the entire flowfield formed the basis for the performance evaluation.

(a) The facility established to investigate the flow conditions in a simulated laser nozzle assembly and lasing cavity is suitable for this type of cold flow investigation.

(b) The nozzles performed at the expected design conditions. Design conditions are established in the nozzle section immediately after flow initiation for various supersonic difusser throat area ratios. Conditions are maintained for various lengths of time and are dependent on the build-up of back pressure within the cavity. Results indicate that the nozzle and base regions followed theory very closely.

(c) The combined Korst general/basic back step theory, when carefully applied, accurately predicts experimental base pressure ratios.

(d) Flow conditions in the cavity, determined by static pressure taps and schlieren photographs, are directly related to the supersonic diffuser throat setting. Settings below the minimum running throat area ratio caused the flow pattern to breakup, opening the base wake regions, and unstarting the nozzle or causing the separation of the flow stream inside the nozzle exit.

(e) Limited data on the supersonic diffuser indicates that it was not operating like the two-dimensional model used to design it, but flow conditions in the cavity were being maintained at operation conditions longer than would be possible without the diffuser. Three–dimensional flow patterns are

suspected to be the main reason why the diffuser did not operate closer to the two–dimensional model.

VII. Recommendations

The study of flow conditions in the cavity of a chemical laser is extremely important to the furthering of chemical laser research. Proper cavity conditions are a must to insure safe and efficient lasing. Cold flow analysis of the cavity flowfield provides a foundation for further hot flow studies and will provide a clearer understanding of complicated flowfields. The following subjects require further investigation:

(a) Install total pressure probe in the cavity section for measurement of total pressure and correlation with static pressure values.

(b) Install pressure devices in the diffuser to describe and analyize the flowfield conditions.

(c) Install additional static pressure ports in the test section sidewall to more completely map out the flowfield.

(d) Install and test an air/helium flow control system that actively monitors and regulates the air/helium mixture through the flow system.

(e) Investigate other nozzle configurations that allow base and hypersonic wedge flow.

Appendix A. *Computer Programs*

A.1 Diffuser Program

To determine the diffuser blade geometry, it was first necessary to know the entrance Mach number to the diffuser, the wedge angle (ω), the specific heat ratio (γ), the number of shocks to be considered, and the diffuser throat area (A_{Dt}). A program was written to calculate the conditions after several oblique shocks. Using the diffuser program, the optimum recovery pressure was determined for various blade geometries. The blade geometries were then compared to the acceptable diffuser overall dimensions, and the best blade design was selected. The following is a copy of the Fortran program used to calculate some of the diffuser shock conditions.

```
C234567
C
C
      PROGRAM DIFFUSER
      IMPLICIT REAL*8 (A-Z)
      INTEGER FLAG,I,N,NEG
      DIMENSION A(4),B(4),C(4),FLAG(10),M(10),PS(10),PT(10),WSA(10),
     1 XR(3),XI(3)
      COMMON K,RAD,DEC
$DEBUG
C
C
C     ******************************************************
C     *              INTERACTIVE INPUT OF KNOWNS.          *
C     ******************************************************
C
      WRITE(*,10)
   10 FORMAT(5X,'ENTER MACH NUMBER 1:  ')
      READ(*,*)MX
      WRITE(*,20)
   20 FORMAT(5X,'ENTER WEDGE ANGLE:  ')
      READ(*,*)WAD
      WRITE(*,30)
   30 FORMAT(5X,'ENTER THROAT WIDTH (INCHES):  ')
      READ(*,*)TW
      WRITE(*,40)
```

```
   40 FORMAT(5X,'ENTER NUMBER OF OBLIQUE SHOCKS TO BE CONSIDERED:  ')
      READ(*,*)N
      WRITE(*,45)
   45 FORMAT(5X,'ENTER GAMMA:  ')
      READ(*,*)K
C
C
C     ******************************************************
C     *                 SET CONSTANTS.                     *
C     ******************************************************
C
      DEG=5.7295779513D1
      RAD=1.745329252D-02
      A1=9.27D0
      AT=TW*9.27D0
C
C
C     ******************************************************
C     *                 INITIALIZE VALUES.                 *
C     ******************************************************
C
      WAR=WAD*RAD
      M(1)=MX
      PTT=1D0
C
C     ******************************************************
C     *    DETERMINE THE ROOTS OF THE POLYNOMIAL USING THE *
C     *    BAIRSTOW'S METHOD.  THE SMALLEST OF THE THREE   *
C     *    ROOTS CORRESPONDS TO A DECREASE IN ENTROPY      *
C     *    AND SHOULD BE DISREGARDED.   THE REMAINING      *
C     *    TWO ROOTS WILL BE THE STRONG AND THE WEAK       *
C     *    SHOCK WAVE ANGLES.                              *
C     ******************************************************
C
      DO 50 I=1,N
         CALL SAMAX(M(I),SAMR)
         CALL WAMAX(SAMR,M(I),WAMR)
      IF(WAR.LE.WAMR)THEN
        CALL PCHAR(WAR,M(I),SSAR,WSAR)
        CALL OBSHOC(WSAR,M(I),MY,PSYX,PTYX)
        M(I+1)=MY
        PS(I)=PSYX
        PT(I)=PTYX
        WSAD=WSAR*DEG
        WSA(I)=WSAD
        FLAG(I)=1
      ENDIF
      IF(WAR.GT.WAMR)THEN
        WRITE(*,60)M(I)
   60   FORMAT(5X,'THE WEDGE ANGLE EXCEDES THE MAXIMUM WEDGE ANGLE',
     1  5X,' FOR MACH #:  ',F5.2)
```

```
          GOTO 1000
        ENDIF
   50 CONTINUE
        CALL MFLUX(M(1),MF1)
        CALL MFLUX(M(N),MFN)
        DO 70 I=1,N
           PTT=PTT*PT(I)
   70 CONTINUE
        AR=AT/A1
        AR1=MF1/(MFN*PTT)
C
C
C       ******************************************************
C       *                    PRINT RESULTS.                  *
C       ******************************************************
C
        WRITE(*,150)AR,AR1,M(N+1),K
  150 FORMAT(11X,'TRUE DIFFUSER AREA RATIO:  ',F6.3,
     1 /,5X,'CALCULATED DIFFUSER AREA RATIO:  ',F6.3,
     2 /,5X,'MACH NUMBER AFTER LAST OBLIQUE SHOCK:  ',
     3 F6.3,/,5X,'RATIO OF SPECIFIC HEATS (GAMMA):  ',F6.3)
        WRITE(*,200)
  200 FORMAT(/,5X,'REGION',5X,'MACH#',9X,'SHOCK ANGLE',7X,' PR STATIC',
     1 9X,'PR TOTAL',/)
        DO 220 I=1,N
        IF(FLAG(I).EQ.0)GOTO 1000
        WRITE(*,210)I,M(I),WSA(I),PS(I),PT(I)
  210 FORMAT(6X,I2,4X,F12.9,4X,F12.9,4X,F13.9,4X,F13.9)
  220 CONTINUE
 1000 STOP
        END
C
        SUBROUTINE MFLUX(M,MF)
        IMPLICIT REAL*8 (A-Z)
        INTEGER I,N,NEG
        COMMON K,RAD,DEG
        MF1=2D0/(K+1D0)
        MF2=((K-1D0)/2D0)*M**2D0
        MF3=-(K+1D0)/((K-1D0)*2D0)
        MF=M*(MF1*(1D0+MF2))**MF3
        RETURN
        END
C
C
C       ******************************************************
C       *               SUBROUTINE PCHAR                     *
C       *                                                    *
C       *  THIS SUBROUTINE CALCULATES THE CHARACTERISTICS    *
C       *  OF THE POLYNOMIAL EQUATION AND THEN CALLS POLY    *
C       *  TC SOLVE THE EQUATION.                            *
C       ******************************************************
```

```
C
      SUBROUTINE PCHAR(WAR,M,SSA,WSA)
      IMPLICIT REAL*8 (A-Z)
      INTEGER I,N,NEG
      DIMENSION A(4),B(4),C(4),XR(3),XI(3)
      COMMON K,RAD,DEG
      N=3
      A(0)=-1D0*(((DCOS(WAR))**2D0)/M**4D0)
      A1A=((2D0*M**2D0)+1D0)/M**4D0
      A1B=((K+1)**2D0)/4D0 + (K-1)/M**2D0
      A(1)=A1A+A1B*(DSIN(WAR))**2D0
      A(2)=-1D0*((M**2D0+2D0)/M**2D0)-(K*(DSIN(WAR))**2D0)
      A(3)=1D0
      CALL POLY(N,A,XR,XI,NEG)
      N=3
      DO 10 I=1,N
         IF(XR(I).LT.0D0)GOTO 10
         XR(I)=DSQRT(XR(I))
         XR(I)=DASIN(XR(I))
         XR(I)=XR(I)*DEG
   10 CONTINUE
      SSA=DMAX1(XR(1),XR(2),XR(3))
      DO 20 I=1,N
         HI1=XR(I)/SSA
         IF(HI1.EQ.1)THEN
         XR(I)=0D0
         ENDIF
   20 CONTINUE
      WSA=DMAX1(XR(1),XR(2),XR(3))
      SSA=SSA*RAD
      WSA=WSA*RAD
      RETURN
      END
C
C
C
C     *******************************************************
C     *                  SUBROUTINE POLY                    *
C     *                                                     *
C     *  THIS SUBROUTINE SOLVES THE THIRD ORDER POLYNOMIAL  *
C     *  FOR THE THREE ROOTS.  TWO OF THE ROOTS ARE THE     *
C     *  STRONG AND WEAK SHOCK ANGLES.  THE THIRD ROOT      *
C     *  THE SMALLEST VALUE CORRESPONDS TO A DECREASE IN    *
C     *  ENTROPY AND SHOULD BE DISREGARDED.                 *
C     *******************************************************
C
      SUBROUTINE POLY(N,A,XR,XI,NEG)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A(4),B(4),C(4),XR(3),XI(3)
      R=-10D0
      S=-10D0
```

```
      MAXIT=100
    5 IF(N.GE.3.AND.ITER.LT.MAXIT)THEN
        ITER=0
        DO 15 J=1,MAXIT
          ITER=ITER+1
          B(N)=A(N)
          B(N-1)=A(N-1)+R*B(N)
          C(N)=B(N)
          C(N-1)=B(N-1)+R*C(N)
          DO 10 I=N-2,0,-1
             B(I)=A(I)+R*B(I+1)+S*B(I+2)
   10        C(I)=B(I)+R*C(I+1)+S*C(I+2)
          DET=(DABS(C(2)))**2D0-C(3)*C(1)
          IF(DET.NE.0D0)THEN
            DR=(-B(1)*C(2)+B(0)*C(3))/DET
            DS=(-B(0)*C(2)+B(1)*C(1))/DET
            EA1=DABS(DR/R)*100D0
            EA2=DABS(DS/S)*100D0
            R=R+DR
            S=S+DS
          ELSE
            R=R+1D0
            S=S+1D0
            ITER=0
          ENDIF
          IF(EA1.LT.1d-02.AND.EA2.LT.1d-02)GOTO 17
   15 CONTINUE
   17   CALL ROOTS(N,R,S,XR,XI,NEG)
        N=N-2
        DO 20 II=0,N
   20      A(II)=B(II+2)
      ENDIF
      IF(N.GE.3)GOTO 5
      IF(ITER.LT.MAXIT)THEN
        IF(N.EQ.2)THEN
          R=A(1)/A(2)
          S=A(0)/A(2)
          CALL ROOTS(N,R,S,XR,XI,NEG)
        ELSE
          XR(1)=-A(0)/A(1)
        ENDIF
      ELSE
        WRITE(*,30)
   30   FORMAT(5X,'MAXIMUM ITERATIONS EXCEEDED!',/)
      ENDIF
      RETURN
      END
C
C
C     ***********************************************************
C     *                   SUBROUTINE ROOTS                      *
```

```
C       *                                                        *
C       *   THIS SUBROUTINE CALCULATES THE ROOTS OF THE          *
C       *   QUADRATIC USING R AND S VALUES CALCULATED BY         *
C       *   SUBROUTINE POLY.                                     *
C       **********************************************************
C
        SUBROUTINE ROOTS(N,R,S,XR,XI,NEG)
        IMPLICIT REAL*8 (A-H,O-Z)
        DIMENSION XR(3),XI(3)
        F=(DABS(R))**2D0+4*S
        NEG=0
        IF(F.LT.0D0)THEN
          F=-F
          NEG=1
        ENDIF
        XR(N)=(R+DSQRT(F))/2D0
        XR(N-1)=(R-DSQRT(F))/2D0
        IF(NEG.EQ.1)THEN
          XR(N)=R/2D0
          XR(N-1)=R/2D0
          XI(N)=DSQRT(F)/2D0
          XI(N-1)=-DSQRT(F)/2D0
        ENDIF
        RETURN
        END
C
C
C       **********************************************************
C       *                 SUBROUTINE OBSHOC                      *
C       *                                                        *
C       *   THIS SUBROUTINE CALCULATES THE MACH NUMBER ON        *
C       *   THE OTHER SIDE OF A OBLIQUE SHOCK WAVE AND THE       *
C       *   STATIC PRESSURE RATIO.                               *
C       **********************************************************
C
        SUBROUTINE OBSHOC (S,MX,MY,PSYX,PTYX)
        IMPLICIT REAL*8 (A-Z)
        COMMON K,RAD,DEG
        MY1=(K+1D0)**2D0
        MY2=MX**4D0
        MY3=MX**2D0
        MY4=DSIN(S)**2D0
        MY5=K-1D0
        MY6=(MY1*MY2*MY4)-4D0*(MY3*MY4-1D0)*(K*MY3*MY4+1D0)
        MY7=(2D0*K*MY3*MY4-MY5)*(MY5*MY3*MY4+2D0)
        MY=DSQRT(MY6/MY7)
        PSYX=(2D0*K*MY3*MY4-MY5)/(K+1D0)
        M1X=MX*DSIN(S)
        PZ1=((K+1D0)/2D0)*M1X**2D0
        PZ2=1+((K-1D0)/2D0)*M1X**2D0
        PZ3=K/(K-1D0)
```

```
      PZ4=1D0/(1D0-K)
      PZ5=(K-1D0)/(K+1D0)
      PZ6=2D0*K*M1X**2D0/(K+1D0)
      PTYX=((PZ1/PZ2)**PZ3)*(PZ6-PZ5)**PZ4
      RETURN
      END
C
C
      SUBROUTINE SAMAX(M,SAM)
      IMPLICIT REAL*8 (A-Z)
      COMMON K,RAD,DEG
      SAM1=3D0*(3D0*M**4D0+4D0*M**2D0+20D0)
      SAM=(1D0/(7D0*M**2D0))*(3D0*M**2D0-5D0+DSQRT(SAM1))
      SAM=DSQRT(SAM)
      SAM=DASIN(SAM)
      RETURN
      END
C
C
      SUBROUTINE WAMAX(SA,M,WAM)
      IMPLICIT REAL*8 (A-Z)
      COMMON K,RA,DEG
      WAM1=M**2D0*((DSIN(SA))**2D0)-1D0
      WAM=DTAN(SA)*(((6D0*M**2D0)/(5D0*(WAM1)))-1D0)
      WAM=DATAN(1D0/WAM)
      RETURN
      END
```

A.2 Data Aquisition Program

The following GW Basic program was written to control the aquisition of the pressure data through the Qua Tech Simultaneous Sampling System. The Qua Tech "LABSIM" (11) program is listed in the begining of the program to establish continuity between the Qua Tech system and the CPU. The remainder of the program specially developed to handle the unique data aquisition system configuration.

```
5 '**************************************************************************
6 '*          LASER CAVITY FLOW DATA AQUISTION PROGRAM (LCFDAP)             *
7 '*                                                                        *
8 '*          WRITTEN BY:  CAPT STEPHEN W. STIGLICH, JR.                    *
9 '*                                                                        *
10 '*          WRITTEN FOR:  THESIS REQUIREMENTS                             *
11 '*          THESIS ADVISOR:  DR. W. C. ELROD                              *
12 '*                                                                        *
13 '*  This program gathers data using a Qua Tech board thru pressure       *
14 '*  transducers located in both stilling chambers and Test Section.      *
15 '**************************************************************************
91 '
92 '              ****************************************
93 '              *  QUA TECH ASSEMBLY LANGUAGE ROUTINES *
94 '              *                                      *
95 '              *  THE FIRST 400 LINES ARE USED TO     *
96 '              *  DEFINE AND LOCATE SPECIAL ASSEMBLY  *
97 '              *  LANGUAGE ROUTINES REQUIRED TO RUN   *
98 '              *  THE QUA TECH BOARDS.   SEE THE QUA  *
99 '              *  MANUALS FOR A DESCRIPTION OF THE    *
100 '              *  THE VARIABLES.                      *
101 '              ****************************************
102 '
220 ADC.SETUP=&H3:SETCTM=&H6
230 SETCO=&H9
240 INADC12.B=&HC:SEGADDR=&HF:INADC12.BB=&H12
250 SETMD1=&H15:SETMD2=&H18:SETC1=&H1B:SETC2=&H1E
260 RSETC1=&H21:RSETC2=&H24:READC1=&H27:READC2=&H2A
270 DEF SEG=0
280 CSEG1=PEEK(&H3CA)+256*PEEK(&H3CB)
380 '
390 '
400 '
410 '              ****************************************
411 '              *         APPLICATION PROGRAM          *
412 '              ****************************************
```

```
420 '
430 ' Before the CALL Statements from each program you must
440 ' redefine the "SEG" statements.
460 ' For Labsim statements use DEF SEG=CSEG1.
480 '
490 '************************************************************
500 '     LASER CAVITY SET-UP    Six channel simultaneous sampling.
510 '  The result of the data are stored in the array sequentially
520 '                array%(1) -- channel 0
530 '                array%(2) -- channel 1
540 '                array%(3) -- channel 2
550 '                array%(4) -- channel 3
560 '                array%(5) -- channel 4
570 '                array%(6) -- channel 5
580 '
640 '************************************************************
1000 '
1005 DIM CHZV#(6),CHV#(6),POSITION%(6),SLOPEPT#(11)
1010 COLOR 7,1:CLS 0
1020 PRINT "                              DATA RUN CONFIGURATION"
1025 PRINT "                                       MENU"
1030 PRINT ""
1035 PRINT "CONFIG #        TRANSDUCER POS. # ASSIGNED TO QUA TECH CHANNEL
#"
1040 PRINT "                   0       1       2       3       4       5"
1045 PRINT ""
1050 PRINT "  1                01      02      03      04      05      06"
1055 PRINT "  2                01      02      15      12      05      06"
1060 PRINT "  3                01      17      14      11      09      06"
1065 PRINT "  4                18      16      03      13      10      06"
1070 PRINT "  5                07      14      15      16      08      06"
1075 PRINT "  6                17      02      18      13      11      06"
1080 PRINT "  7                OPERATOR ASSIGNED."
1085 PRINT ""
1090 INPUT "SELECT THE CONFIGURATION FOR THIS RUN.  ",CONF%
1100 IF CONF%=1 THEN GOSUB 10000
1110 IF CONF%=2 THEN GOSUB 20000
1120 IF CONF%=3 THEN GOSUB 30000
1130 IF CONF%=4 THEN GOSUB 40000
1140 IF CONF%=5 THEN GOSUB 50000
1150 IF CONF%=6 THEN GOSUB 60000
1160 IF CONF%=7 THEN GOSUB 65000
2000 '
2010 CLS 0
2015 SLOPEPT#(2)=2.39741157912
2016 SLOPEPT#(8)=3.11210203183
2020 SAMPLERATE%=200
2021 SEC=15
2030 INPUT "DO YOU WANT TO TAKE A NEW ZERO RUN (YES=Y, NO=N)";Z$:PRINT ""
2031 IF Z$="N" OR Z$="n" THEN GOTO 2100
2032 INPUT "ENTER FILENAME FOR ZERO RUN DATA:  ", ZD1$:PRINT ""
```

```
2033 ZD1$="C:\SWS\DATA1\"+ZD1$+".DAT"
2060 COLOR 19,1:CLS 0:PRINT "":PRINT "":PRINT "":PRINT ""
2070 PRINT "                          ************************************"
2071 PRINT "                          *  ZERO VOLTAGE RUN IN PROGRESS!  *"
2072 PRINT "                          ************************************"
2073 ZDATE$=DATE$
2074 ZTIME$=TIME$
2075 GOSUB 5000
2080 '
2081 OPEN ZD1$ FOR OUTPUT AS #1
2082 PRINT #1,"                   ZERO VOLTAGE RUN"
2083 PRINT #1,""
2084 PRINT #1,"DATE OF RUN:  ";ZDATE$
2085 PRINT #1,"TIME OF RUN:  ";ZTIME$
2086 PRINT #1,""
2087 FOR I=1 TO 6
2088     PRINT #1,CHZV#(I)
2089 NEXT I:CLOSE #1
2090 COLOR 31,1:CLS 0:PRINT "":PRINT "":PRINT "":PRINT ""
2091 PRINT "                          ************************************"
2092 PRINT "                          *   ZERO VOLTAGE RUN COMPLETED!   *"
2093 PRINT "                          ************************************"
2094 PRINT
2095 PRINT:COLOR 7,1
2096 GOTO 2110
2100 INPUT "ENTER FILENAME OF ZERO DATA FILE TO USE:  ",ZD2$:PRINT ""
2101 ZD2$="C:\SWS\DATA1\"+ZD2$+".DAT"
2102 OPEN ZD2$ FOR INPUT AS #1
2103 FOR I=1 TO 5
2104     LINE INPUT #1, JUNK$
2105 NEXT I
2106 FOR I=1 TO 6
2107    INPUT #1, CHZV#(I)
2108 NEXT I
2109 CLOSE #1:ZD1$=ZD2$
2110 INPUT "FILENAME FOR DATA (EXTENSION WILL BE .DAT)";N$:PRINT ""
2113 N$="C:\SWS\DATA1\"+N$+".DAT"
2114 INPUT "ENTER THE DIFFUSER THROAT WIDTH (INCHES)";TW#:PRINT ""
2115 PRINT "TEST LENGTH = ";SEC;" SECONDS":PRINT ""
2116 INPUT "DO YOU WANT TO CHANGE THE TEST LENGTH (YES=Y, NO=N)";TL$:PRINT
""
2117 IF TL$="N" OR TL$="n" THEN 2119
2118 INPUT "ENTER NEW TEST LENGTH.  ",SEC:PRINT ""
2119 PRINT "SAMPLE RATE = ";SAMPLERATE%:PRINT ""
2120 INPUT "DO YOU WANT TO CHANGE THE SAMPLE RATE (YES=Y, NO=N)";SR$:PRINT
""
2121 IF SR$="N" OR SR$="n" THEN 2125
2122 INPUT "ENTER NEW SAMPLE RATE.  ",SAMPLERATE%:PRINT ""
2125 INPUT "TURN ON LAB VACUUM PUMPS, THEN PRESS RETURN.";DUMMY$:PRINT ""
2126 INPUT "TURN ON REF VACUUM PUMP, THEN PRESS RETURN.";DUMMY$:PRINT ""
2127 INPUT "ENTER REFERENCE PRESSURE   (MM OF HG):  ";PREF#:PRINT ""
```

```
2128 PREF#=PREF#*.019264
2130 GOSUB 8000
2150 INPUT "ENTER ATMOSPHERIC PRESSURE (IN OF HG):  ";PATM#:PRINT ""
2160 INPUT "ENTER REFERENCE PRESSURE   (MM OF HG):  ";PREF#:PRINT ""
2170 PATM#=PATM#*.4893
2180 PREF#=PREF#*.019264
2190 POINTS%=SEC*SAMPLERATE%
2191 DIMA%=POINTS%*6
2192 TESTDATE$=DATE$
2193 INPUT "PRESS RETURN TO START DATA RUN.";DUMMY$
2195 TESTTIME$=TIME$
2196 COLOR 19,1:CLS 0:PRINT "":PRINT "":PRINT "":PRINT ""
2197 PRINT "                          ***********************************"
2198 PRINT "                          *       DATA RUN IN PROGRESS!     *"
2199 PRINT "                          ***********************************"
2200 GOSUB 6000
2201 COLOR 31,1:CLS 0:PRINT "":PRINT "":PRINT "":PRINT ""
2202 PRINT "                          ***********************************"
2203 PRINT "                          *        DATA RUN COMPLETE!       *"
2204 PRINT "                          *                                 *"
2205 PRINT "                          *      PRINTING DATA TO FILE      *
2207 PRINT "                          ***********************************"
2208 PRINT
2209 PRINT:COLOR 7,1
2210 OPEN N$ FOR OUTPUT AS #1
2211 PRINT #1,"                                 TEST DATA RUN"
2212 PRINT
#1,POSITION%(1),POSITION%(2),POSITION%(3),POSITION%(4),POSITION%(5),POSITIO
N%(6)
2213 PRINT #1,SEC,TW#
2216 PRINT #1,SAMPLERATE%
2217 PRINT #1,TESTDATE$,TESTTIME$
2218 PRINT #1,CHZV#(1) CHZV#(2) CHZV#(3) CHZV#(4) CHZV#(5) CHZV#(6)
2219 PRINT #1,PATM#,PREF#
2220 INDEX%=1
2221 FOR J=1 TO DIMA%
2222     PRINT #1,ARRAY%(J);" ";
2223     INDEX%=INDEX%+1
2224     IF INDEX%=7 THEN PRINT #1,""
2225     IF INDEX%=7 THEN INDEX%=1
2228 NEXT J
2229 CLOSE #1
2300 HISZ$="C:\SWS\HIS\HISZ.DAT"
2310 OPEN HISZ$ FOR APPEND AS #1
2320 PRINT #1,ZD1$
2330 CLOSE #1
2400 HIST$="C:\SWS\HIS\HIST.DAT"
2410 OPEN HIST$ FOR APPEND AS #1
2420 PRINT #1,N$
2430 CLOSE #1
2900 CLS 0
```

```
2920 COLOR 15,1: PRINT "":PRINT ""
2930 SOUND 2600,10
2950 INPUT "DO YOU WANT TO TAKE ANOTHER DATA RUN? ";ANS$:CLS 0
2960 IF ANS$="N" OR ANS$="n" THEN GOTO 3000
2970 ERASE ARRAY%:GOTO 1010
3000 CLS 0:CLEAR:SYSTEM
5000 '
5010 '***************************************************************
5020 '*                    SUBROUTINE ZERO                           *
5030 '*                                                              *
5040 '*  This subroutine samples the pressure transducers and        *
5050 '*  calculates the zero voltages prior to taking a run.         *
5060 '***************************************************************
5070 '
5100 DEF SEG=CSEG1                              'DEFINE THE A TO D CARD
5110 DIM ARRAY%(20000)
5120 ADDRESS%=&H300
5130 N%=6                                       '# OF CHANNELS
5140 CALL ADC.SETUP(ADDRESS%,N%)
5150 CO%=5000000!/20000                         '20KHZ SAMPLING RATE
5160 CALL SETCO(CO%)
5170 LENGTH%=100                                'TAKE 100 POINTS
5180 LENGTH%=LENGTH%*6
5190 S#=LENGTH%/6
5200 CALL INADC12.B(LENGTH%,ARRAY%(1))          'TAKE ZERO VOLTAGES DATA
5210 FOR I=1 TO 6
5220     CHZV#(I)=0!
5230 NEXT I
5270 FOR J=1 TO  6
5275     FOR I=1+(J-1) TO 595+(J-1) STEP 6
5280         CHZV#(J)=(2047-ARRAY%(I))/819.2+CHZV#(J)      'CONVERT TO
VOLTAGES
5340     NEXT I
5345 NEXT J
5350 '
5360 '
5370 '
5380 FOR I=1 TO 6
5390     CHZV#(I) = CHZV#(I)/S#                    'PSIG TRANSDUCER
5400 NEXT I
5435 '
5460 ERASE ARRAY%
5465 RETURN
6000 '
6010 '***************************************************************
6020 '*                    SUBROUTINE PRES                           *
6030 '*                                                              *
6040 '*  This subroutine samples the pressure transducers and        *
6050 '*  calculates the pressure voltages.                           *
6060 '***************************************************************
6070 '
```

```
6100 DEF SEG=CSEG1                              'DEFINE THE A TO D CARD
6110 DIM ARRAY%(DIMA%)
6120 ADDRESS%=&H300
6130 N%=6                                       '# OF CHANNELS
6140 CALL ADC.SETUP(ADDRESS%,N%)
6150 CO%=5000000!/SAMPLERATE%                   '5MHZ/SAMPLING RATE
6160 CALL SETCO(CO%)
6170 LENGTH%=POINTS%                            'TAKE SO MANY POINTS PER CHNL
6200 CALL INADC12.B(LENGTH%,ARRAY%(1))          'TAKE PRES VOLTAGES DATA
6470 RETURN
8000 '
8001 '************************************************************
8002 '*             SUBROUTINE TEST SECTION PRESSURE             *
8003 '*                                                          *
8004 '*  This subroutine samples the pressure transducer in the  *
8005 '*  test section and gives the operator a pressure value.   *
8006 '*  This allows the operator to monitor the test section    *
8007 '*  pressure and determine when he is ready to make a run.  *
8008 '************************************************************
8009 '
8025 CLS 0
8050 VIEW PRINT 1 TO 15
8055 SLOPE#=SLOPEPT#(2)
8060 IF POSITION%(2) > 2 THEN SLOPE#=SLOPEPT#(8)
8080 LOCATE 5,20
8090 COLOR 16,1
8100 PRINT "*************************************"
8105 LOCATE 6,20
8110 PRINT "* PRESS RETURN ONCE VACUUM IN TEST  *"
8115 LOCATE 7,20
8120 PRINT "* SECTION HAS STABILIZED.           *"
8125 LOCATE 8,20
8130 PRINT "*************************************"
8200 VIEW PRINT 11 TO 12
8210 COLOR 15,1
8300 P$=INKEY$:IF LEN(P$)<>0 THEN 8900
8310 DEF SEG=CSEG1                              'DEFINE THE A TO D CARD
8320 DIM ARRAY%(20000)
8330 ADDRESS%=&H300
8340 N%=6                                       '# OF CHANNELS
8350 CALL ADC.SETUP(ADDRESS%,N%)
8360 CO%=5000000!/20000                         '20KHZ SAMPLING RATE
8370 CALL SETCO(CO%)
8380 LENGTH%=100                                'TAKE 100 POINTS
8390 LENGTH%=LENGTH%*N%
8400 S#=LENGTH%/N%
8410 CALL INADC12.B(LENGTH%,ARRAY%(1))          'TAKE ZERO VOLTAGES DATA
8420 FOR I=1 TO N%
8430     CHV#(I)=0!
8440 NEXT I
8450 FOR J=1 TO  N%
```

```
8460     FOR I=1+(J-1) TO 595+(J-1) STEP 6
8470         CHV#(J)=(2047-ARRAY%(I))/819.2!+CHV#(J)      'CONVERT TO
VOLTAGES
8480     NEXT I
8490 NEXT J
8500 '
8510 '
8520 '
8530 FOR I=1 TO 6
8540     CHV#(I) = CHV#(I)/S#                      'PSIG TRANSDUCER
8550 NEXT I
8560 '
8570 ERASE ARRAY%
8600 CHV#(2)=CHV#(2)-CHZV#(2)
8610 PCH2G#=CHV#(2)*SLOPE#
8620 PCH2A#=PREF#+PCH2G#
8710 PRINT "TEST CHAMBER STAGNATION PRESSURE IS:  ";
8715 PRINT USING "####.#####";PCH2A#;
8716 PRINT " PSIA"
8718 IF PCH2A# < .1350 THEN SOUND 2600,10
8720 GOTO 8300
8900 VIEW PRINT 1 TO 25:CLS 0
8950 RETURN
10000 '
10010 POSITION%(1)=01
10020 POSITION%(2)=02
10030 POSITION%(3)=03
10040 POSITION%(4)=04
10050 POSITION%(5)=05
10060 POSITION%(6)=06
10100 RETURN
20000 '
20010 POSITION%(1)=01
20020 POSITION%(2)=02
20030 POSITION%(3)=15
20040 POSITION%(4)=12
20050 POSITION%(5)=05
20060 POSITION%(6)=06
20100 RETURN
30000 '
30010 POSITION%(1)=01
30020 POSITION%(2)=17
30030 POSITION%(3)=14
30040 POSITION%(4)=11
30050 POSITION%(5)=09
30060 POSITION%(6)=06
30100 RETURN
40000 '
40010 POSITION%(1)=18
40020 POSITION%(2)=16
40030 POSITION%(3)=03
```

```
40040 POSITION%(4)=13
40050 POSITION%(5)=10
40060 POSITION%(6)=06
40100 RETURN
50000 '
50010 POSITION%(1)=07
50020 POSITION%(2)=14
50030 POSITION%(3)=15
50040 POSITION%(4)=16
50050 POSITION%(5)=08
50060 POSITION%(6)=06
50100 RETURN
60000 '
60010 POSITION%(1)=17
60020 POSITION%(2)=02
60030 POSITION%(3)=18
60040 POSITION%(4)=13
60050 POSITION%(5)=11
60060 POSITION%(6)=06
60100 RETURN
65000 '
65002 CLS 0
65010 PRINT "               OPERATOR ASSIGNED CONFIGURATION"
65020 PRINT "                         MENU"
65030 PRINT ""
65040 PRINT "               CURRENT QUA TECH CHNL ASSIGNMENTS:
65050 PRINT ""
65060 PRINT "               CHANNEL #                POSITION #"
65070 PRINT ""
65075 PRINT "                  0                   ";POSITION%(1)
65076 PRINT "                  1                   ";POSITION%(2)
65077 PRINT "                  2                   ";POSITION%(3)
65078 PRINT "                  3                   ";POSITION%(4)
65079 PRINT "                  4                   ";POSITION%(5)
65080 PRINT "                  5                   ";POSITION%(6)
65085 PRINT ""
65090 PRINT "ENTER CHANNEL # TO CHANGE OR ENTER 9 WHEN COMPLETE."
65095 INPUT "REMEMBER TO INPUT TWO DIGITS (EXAMPLE: 01 OR 18).  ",OPC%
65100 IF OPC%=0 THEN INPUT "ENTER POSITION ASSIGNMENT FOR CHANNEL 0.
",POSITION%(1)
65110 IF OPC%=1 THEN INPUT "ENTER POSITION ASSIGNMENT FOR CHANNEL 1.
",POSITION%(2)
65120 IF OPC%=2 THEN INPUT "ENTER POSITION ASSIGNMENT FOR CHANNEL 2.
",POSITION%(3)
65130 IF OPC%=3 THEN INPUT "ENTER POSITION ASSIGNMENT FOR CHANNEL 3.
",POSITION%(4)
65140 IF OPC%=4 THEN INPUT "ENTER POSITION ASSIGNMENT FOR CHANNEL 4.
",POSITION%(5)
65150 IF OPC%=5 THEN INPUT "ENTER POSITION ASSIGNMENT FOR CHANNEL 5.
",POSITION%(6)
65160 IF OPC%=9 THEN GOTO 65180
```

```
65170 GOTO 65000
65180 RETURN
```

A.3 Data Reduction and System Control Program

This Quick Basic program controls of both the data aquisition and the data reduction. It also provides the capability to plot the reduced data files. The operator needs only enter *Laser* and follow the procedures outline on the screen. Subroutine Axis was provided by Tanis (15).

```
DECLARE SUB VOLTAGE (CH!(), ARRAY%(), DIMA%, N%, FLAG%, T%, TS%, I1%, I2%)
DECLARE SUB PLOTMENU (TDC$, CHNL$)
DECLARE SUB CHANNEL (TDC$, CHNL$, TIME!(), PRES!())
DECLARE SUB MAINMENU ()
DECLARE SUB DATARUN ()
DECLARE SUB DATACONV ()
DECLARE SUB PLOTDATA ()
DECLARE SUB MAXIMUM (max, DMAX!(), TSTEP%)
DECLARE SUB AXIS (XMAX!, XMIN!, YMAX!, YMIN!)
DECLARE SUB MINIMUM (min, DMIN!(), TSTEP%)
COMMON SHARED SAMPLERATE%, N%, SEC, TSTEP%
SCREEN 9
COLOR 7, 1
SEC = 15
CALL MAINMENU
SCREEN 0
CLS 0
COLOR 1, 1
END

SUB AXIS (XMAX, XMIN, YMAX, YMIN) STATIC
DIM X(0 TO 6), y(0 TO 6)
EGA$ = "Y"
        VIEW PRINT 1 TO 24
        DX = (XMAX - XMIN) / 5
        DY = (YMAX - YMIN) / 5
        FOR I = 0 TO 5
                X(I) = I * DX + XMIN
                y(I) = I * DY + YMIN
        NEXT I
        FOR I = 5 TO 0 STEP -1
                LOCATE 18 - I * 3, 1
                PRINT USING "#.##^^^^"; y(I)
        NEXT I
        XI = 7
        LOCATE 20, 1
        PRINT TAB(XI);
        FOR I = 0 TO 5
                PRINT TAB(XI + 13 * I);
                PRINT USING "#.##^^^^ "; X(I);
```

```
        NEXT I
        PRINT

        'SETS VIEW PORT FOR CGA

        IF EGA$ = "Y" THEN VIEW (70, 35)-(590, 254) ELSE VIEW (70,
20)-(590, 145)

        'DRAWS TIC MARKS FOR THE AXIS
        IF EGA$ = "Y" THEN
        DRAW "BM77,35;NL7"
        FOR I = 0 TO 4
                DRAW "BM+0,11;NL3"
                DRAW "BM+0,10;NL3"
                DRAW "BM+0,11;NL3"
                DRAW "BM+0,10;NL7"
        NEXT I
        ELSE DRAW "BM77,20;NL7"
        FOR I = 0 TO 4
                DRAW "BM+0,6;NL3"
                DRAW "BM+0,6;NL3"
                DRAW "BM+0,6;NL3"
                DRAW "BM+0,6;NL7"
        NEXT I
        END IF
        IF EGA$ = "Y" THEN DRAW "BM80,247;ND6" ELSE DRAW "BM80,141;ND6"
        FOR I = 0 TO 5
                DRAW "BM+25,0;ND2"
                DRAW "BM+26,0;ND2"
                DRAW "BM+25,0;ND2"
                DRAW "BM+26,0;ND7"
        NEXT I

        'SETS VIEW PORT FOR PLOTING THE DATA

        IF EGA$ = "Y" THEN
                 VIEW (80, 35)-(590, 245), 9, 11
        ELSE VIEW (80, 20)-(590, 140), , 2
        END IF

        'SETS SCALE OF THE VIEW PORT

        'WINDOW (-2,0)-(6.5,4.75)
        WINDOW (XMIN, YMIN)-(XMAX, YMAX)
'        LINE (XMIN,0)-(XMAX,0)
        VIEW PRINT 21 TO 24
END SUB

SUB CHANNEL (TDC$, CHNL$, TIME!(), PRES!())
    pfil$ = "C:\SWS\DATA1\" + TDC$ + CHNL$ + ".DAT"
    OPEN pfil$ FOR INPUT AS #20
```

```
          INPUT #20, TSTEP%
          FOR I = 1 TO TSTEP%
               INPUT #20, TIME!(I)
               INPUT #20, PRES!(I)
          NEXT I
     CLOSE #20
     END SUB

SUB DATACONV
DIM CH!(6), CHZV!(6), PCHG!(6), PCHA!(6), ARRAY%(18000), SLOPEPT!(11),
POSITION%(6)
     CLS 0
     INPUT "Enter the number of samples per point on the graph.  ", TS%
     HIS$ = "C:\SWS\HIS\HIST.DAT"
     N% = 6
     SCREEN 0
     COLOR 7, 1
     CLS 0
     OPEN HIS$ FOR INPUT AS #1
     DO UNTIL EOF(1)
        LINE INPUT #1, DATAFILNAM$
        FILNAME$ = RIGHT$(DATAFILNAM$, 10)
        CLS 0
        COLOR 23
        LOCATE 8, 25
        PRINT "READING DATA FILE " + FILNAME$ + "";
        TESTD$ = "C:\SWS\DATA1\" + FILNAME$ + ""
        OPEN TESTD$ FOR INPUT AS #2
        FOR I = 1 TO 7
            IF I = 1 THEN
                LINE INPUT #2, JUNK$
            END IF
            IF I = 2 THEN
                INPUT #2, POSITION%(1), POSITION%(2), POSITION%(3),
POSITION%(4), POSITION%(5), POSITION%(6)
            END IF
            IF I = 3 THEN
                INPUT #2, SEC, TW!
            END IF
            IF I = 4 THEN
                INPUT #2, SAMPLERATE%
            END IF
            IF I = 5 THEN
                INPUT #2, DATETIME$
                DATE$ = LEFT$(DATETIME$, 10)
                TIME$ = RIGHT$(DATETIME$, 8)
            END IF
            IF I = 6 THEN
                INPUT #2, CHZV!(1), CHZV!(2), CHZV!(3), CHZV!(4), CHZV!(5),
CHZV!(6)
            END IF
```

```
    IF I = 7 THEN
        INPUT #2, PATM!, PREF!
    END IF
NEXT I
POINTS% = SEC * SAMPLERATE%
DIMA% = POINTS% * N%
FOR I = 1 TO DIMA%
        INPUT #2, ARRAY%(I)
NEXT I
CLOSE #2
CLS 0
COLOR 23
LOCATE 8, 25
PRINT "CONVERTING/SAVING DATA FILE " + FILNAME$ + "";
SLOPEPT!(1) = 3.532384
SLOPEPT!(2) = 2.397412
SLOPEPT!(3) = 3.333312
SLOPEPT!(4) = 2.804098
SLOPEPT!(5) = 12.61
SLOPEPT!(6) = 53.58949
SLOPEPT!(7) = 4.205204
SLOPEPT!(8) = 3.113102
SLOPEPT!(9) = 3.069795
SLOPEPT!(10) = 2.804098
SLOPEPT!(11) = 3.672596
TSTEP% = (SAMPLERATE% * SEC) / TS%
TD$ = LEFT$(FILNAME$, 6)
POST1$ = LTRIM$(STR$(POSITION%(1)))
POST2$ = LTRIM$(STR$(POSITION%(2)))
POST3$ = LTRIM$(STR$(POSITION%(3)))
POST4$ = LTRIM$(STR$(POSITION%(4)))
POST5$ = LTRIM$(STR$(POSITION%(5)))
POST6$ = LTRIM$(STR$(POSITION%(6)))
IF POSITION%(1) < 10 THEN
   POST1$ = "0" + POST1$ + ""
END IF
IF POSITION%(2) < 10 THEN
   POST2$ = "0" + POST2$ + ""
END IF
IF POSITION%(3) < 10 THEN
   POST3$ = "0" + POST3$ + ""
END IF
IF POSITION%(4) < 10 THEN
   POST4$ = "0" + POST4$ + ""
END IF
IF POSITION%(5) < 10 THEN
   POST5$ = "0" + POST5$ + ""
END IF
IF POSITION%(6) < 10 THEN
   POST6$ = "0" + POST6$ + ""
END IF
```

```
TDCH1$ = "C:\SWS\DATA1\" + TD$ + POST1$ + ".DAT"
TDCH2$ = "C:\SWS\DATA1\" + TD$ + POST2$ + ".DAT"
TDCH3$ = "C:\SWS\DATA1\" + TD$ + POST3$ + ".DAT"
TDCH4$ = "C:\SWS\DATA1\" + TD$ + POST4$ + ".DAT"
TDCH5$ = "C:\SWS\DATA1\" + TD$ + POST5$ + ".DAT"
TDCH6$ = "C:\SWS\DATA1\" + TD$ + POST6$ + ".DAT"
OPEN "C:\SWS\HIS\HISP.DAT" FOR APPEND AS #3
     PRINT #3, "" + TD$ + POST1$ + ""
     PRINT #3, "" + TD$ + POST2$ + ""
     PRINT #3, "" + TD$ + POST3$ + ""
     PRINT #3, "" + TD$ + POST4$ + ""
     PRINT #3, "" + TD$ + POST5$ + ""
     PRINT #3, "" + TD$ + POST6$ + ""
CLOSE #3
OPEN TDCH1$ FOR OUTPUT AS #4
     PRINT #4, TSTEP%
CLOSE #4
OPEN TDCH2$ FOR OUTPUT AS #4
     PRINT #4, TSTEP%
CLOSE #4
OPEN TDCH3$ FOR OUTPUT AS #4
     PRINT #4, TSTEP%
CLOSE #4
OPEN TDCH4$ FOR OUTPUT AS #4
     PRINT #4, TSTEP%
CLOSE #4
OPEN TDCH5$ FOR OUTPUT AS #4
     PRINT #4, TSTEP%
CLOSE #4
OPEN TDCH6$ FOR OUTPUT AS #4
     PRINT #4, TSTEP%
CLOSE #4
OPEN "C:\SWS\RPT\" + TD$ + ".FIL" FOR OUTPUT AS #5
     PRINT #5, "                              DATA RUN " + TD$ + "
RESULTS"
     PRINT #5, ""
     PRINT #5, "DATE:                          "; DATE$
     PRINT #5, "TIME:                          "; TIME$
     PRINT #5, "ATMOSPHERIC PRESSURE:  "; PATM!
     PRINT #5, "REFERENCE PRESSURE:    "; PREF!
     PRINT #5, "DIFFUSER AREA RATIO:   "; TW!
     PRINT #5, "SAMPLE RATE:           "; SAMPLERATE%
     PRINT #5, ""
     PRINT #5, "TIME (SEC)                            POSITION"
     PRINT #5, SPC(15); POST1$; SPC(7); POST2$; SPC(7);
     PRINT #5, POST3$; SPC(7); POST4$; SPC(7);
     PRINT #5, POST5$; SPC(7); POST6$
     PRINT #5, ""
CLOSE #5
FOR T% = 1 TO TSTEP%
FLAG% = N% * TS%
```

```
CALL VOLTAGE(CH!(), ARRAY%(), DIMA%, N%, FLAG%, T%, TS%, I1%, I2%)
FOR I = 1 TO N%
    CH!(I) = CH!(I) - CHZV!(I)
NEXT I
FOR I = 1 TO N%
    SLP% = I
    IF POSITION%(I) > 6 THEN SLP% = I + 6
    PCHG!(I) = CH!(I) * SLOPEPT!(SLP%)
NEXT I
PCHA!(1) = PREF! + PCHG!(1)
PCHA!(2) = PREF! + PCHG!(2)
PCHA!(3) = PREF! + PCHG!(3)
PCHA!(4) = PATM! + PCHG!(4)
IF POSITION%(4) > 4 THEN
   PCHA!(4) = PREF! + PCHG!(4)
END IF
PCHA!(5) = PATM! + PCHG!(5)
IF POSITION%(5) > 5 THEN
   PCHA!(5) = PREF! + PCHG!(5)
END IF
PCHA!(6) = PATM! + PCHG!(6)
TIM! = CDBL((1 / SAMPLERATE%) * T% * TS%)
OPEN TDCH1$ FOR APPEND AS #3
     PRINT #3, USING "###.#####"; TIM!;
     PRINT #3, USING "###.#####"; PCHA!(1)
CLOSE #3
OPEN TDCH2$ FOR APPEND AS #4
     PRINT #4, USING "###.#####"; TIM!;
     PRINT #4, USING "###.#####"; PCHA!(2)
CLOSE #4
OPEN TDCH3$ FOR APPEND AS #5
     PRINT #5, USING "###.#####"; TIM!;
     PRINT #5, USING "###.#####"; PCHA!(3)
CLOSE #5
OPEN TDCH4$ FOR APPEND AS #6
     PRINT #6, USING "###.#####"; TIM!;
     PRINT #6, USING "###.#####"; PCHA!(4)
CLOSE #6
OPEN TDCH5$ FOR APPEND AS #7
     PRINT #7, USING "###.#####"; TIM!;
     PRINT #7, USING "###.#####"; PCHA!(5)
CLOSE #7
OPEN TDCH6$ FOR APPEND AS #8
     PRINT #8, USING "###.#####"; TIM!;
     PRINT #8, "  ";
     PRINT #8, USING "###.#####"; PCHA!(6)
CLOSE #8
OPEN "C:\SWS\RPT\" + TD$ + ".FIL" FOR APPEND AS #5
      PRINT #5, USING "###.#####"; TIM!;
      PRINT #5, " ";
      PRINT #5, USING "###.#####"; PCHA!(1); PCHA!(2); PCHA!(3);
```

```
PCHA!(4); PCHA!(5); PCHA!(6)
        CLOSE #5
        PER! = CSNG(100 * T% / TSTEP%)
        VIEW PRINT 12 TO 13
        CLS
        LOCATE 12, 25
        PRINT "File "; PER!; " % COMPLETE!"
        VIEW PRINT 1 TO 25
        NEXT T%
        LOOP
        CLOSE #1
        SHELL "CD\SWS\HIS"
        SHELL "ERASE HIST.DAT"
        COLOR 7
        CLS 0
        END SUB

SUB DATARUN
        SHELL "CD\SWS"
        SHELL "LABSIM"
        SHELL "BASICA LCF3.BAS"
        CLS 0
        SCREEN 0
        COLOR 7, 1
END SUB

SUB MAINMENU
100     CLS 0
        VIEW PRINT 1 TO 25
        PRINT "                 Main Menu Selections"
        PRINT
        PRINT "1.  Data Run"
        PRINT "2.  Data Conversion"
        PRINT "3.  Plot Data"
        PRINT "4.  Exit Program"
        PRINT
        INPUT "Enter the number of the selection you would like."; sel%
        IF sel% = 1 THEN
           CALL DATARUN
           GOTO 100
        END IF
        IF sel% = 2 THEN
           CALL DATACONV
           SOUND 2600, 10
           GOTO 100
        END IF
        IF sel% = 3 THEN
           CALL PLOTDATA
           GOTO 100
        END IF
        END SUB
```

```
SUB MAXIMUM (max, DMAX!(), S1%)
max = 0
FOR K = 1 TO S1%
    DMAX(K) = CSNG(DMAX!(K))
NEXT K
FOR K = 1 TO S1%
    IF DMAX(K) > max THEN max = DMAX(K)
NEXT K
END SUB

SUB MINIMUM (min, DMIN!(), S1%)
min = 0
FOR l = 1 TO S1%
    DMIN(K) = CSNG(DMIN!(K))
NEXT l
FOR l = 1 TO S1%
    IF DMIN(l) < min THEN min = DMIN(l)
NEXT l
END SUB

SUB PLOTDATA
250  CALL PLOTMENU(TDC$, CHNL$)
     CLS 0
     END SUB

SUB PLOTMENU (TDC$, CHNL$)
        DIM TIME!(800), PRES!(800), POSITION%(6)
        CLS 0
        VIEW PRINT 1 TO 25
        CHNL$ = ""
        PRINT "": PRINT "": PRINT ""
        PRINT "": PRINT ""
215     PRINT "Enter test run are you interested in or hit (Enter) to"
        INPUT "return to the Main Menu"; TDC$
        IF TDC$ = "" THEN
           CHNL$ = "7"
           GOTO 240
        END IF
200     CLS 0
        VIEW PRINT 1 TO 25
        TDC1$ = "" + TDC$ + ".DAT"
        OPEN "C:\SWS\DATA1\" + TDC1$ + "" FOR INPUT AS #5
              LINE INPUT #5, JUNK$
              INPUT #5, POSITION%(1), POSITION%(2), POSITION%(3),
POSITION%(4), POSITION%(5), POSITION%(6)
        CLOSE #5
        PRINT ""
        PRINT "                  Plot Menu Selections"
        PRINT
        PRINT "1.  Plot channel 1 (Position:  "; POSITION%(1); ")"
```

```
PRINT "2.  Plot channel 2 (Position:  "; POSITION%(2); ")"
PRINT "3.  Plot channel 3 (Position:  "; POSITION%(3); ")"
PRINT "4.  Plot channel 4 (Position:  "; POSITION%(4); ")"
PRINT "5.  Plot channel 5 (Position:  "; POSITION%(5); ")"
PRINT "6.  Plot channel 6 (Position:  "; POSITION%(6); ")"
PRINT "7.  Enter different test run."
PRINT "8.  Exit Plot Program."
PRINT
INPUT "Enter the item number you would like to view.  "; sel%
IF sel% = 1 THEN
   CHNL$ = LTRIM$(STR$(POSITION%(1)))
   IF POSITION%(1) < 10 THEN
      CHNL$ = "0" + CHNL$ + ""
   END IF
   GOTO 225
END IF
IF sel% = 2 THEN
   CHNL$ = LTRIM$(STR$(POSITION%(2)))
   IF POSITION%(2) < 10 THEN
      CHNL$ = "0" + CHNL$ + ""
   END IF
   GOTO 225
END IF
IF sel% = 3 THEN
   CHNL$ = LTRIM$(STR$(POSITION%(3)))
   IF POSITION%(3) < 10 THEN
   CHNL$ = "0" + CHNL$ + ""
   END IF
   GOTO 225
END IF
IF sel% = 4 THEN
   CHNL$ = LTRIM$(STR$(POSITION%(4)))
   IF POSITION%(4) < 10 THEN
      CHNL$ = "0" + CHNL$ + ""
   END IF
   GOTO 225
END IF
IF sel% = 5 THEN
   CHNL$ = LTRIM$(STR$(POSITION%(5)))
   IF POSITION%(5) < 10 THEN
      CHNL$ = "0" + CHNL$ + ""
   END IF
   GOTO 225
END IF
IF sel% = 6 THEN
   CHNL$ = LTRIM$(STR$(POSITION%(6)))
   IF POSITION%(6) < 10 THEN
      CHNL$ = "0" + CHNL$ + ""
   END IF
   GOTO 225
END IF
```

```
        IF sel% = 7 THEN
           GOTO 215
        END IF
        IF sel% = 8 THEN
           CHNL$ = "7"
           GOTO 240
        END IF
225     CALL CHANNEL(TDC$, CHNL$, TIME!(), PRES!())
        CALL MAXIMUM(PMAX, PRES!(), TSTEP%)
        CALL MINIMUM(PMIN, PRES!(), TSTEP%)
        CALL MAXIMUM(TMAX, TIME!(), TSTEP%)
        CALL MINIMUM(TMIN, TIME!(), TSTEP%)
        CLS 0
        SCREEN 9
        PRINT TMAX, TMIN, PMAX, PMIN
        AXIS TMAX, TMIN, PMAX, PMIN
        FOR J = 1 TO TSTEP%
            IF J = 1 THEN LINE (TIME!(J), PRES!(J))-(TIME!(J), PRES!(J))
            LINE -(TIME!(J), PRES!(J))
        NEXT J
        DO
        A$ = INKEY$
        LOOP UNTIL A$ <> ""
        GOTO 200
240  END SUB

     SUB VOLTAGE (CH!(), ARRAY%(), DIMA%, N%, FLAG%, T%, TS%, I1%, I2%)
'
'    ***************************************************************
'    *                     SUBROUTINE VOLTAGE                      *
'    *                                                             *
'    *  This subroutine takes the binary values of the sampled     *
'    *  and calculates the corresponding voltages.                 *
'    ***************************************************************
'

     FOR I = 1 TO N%
         CH!(I) = 0!
     NEXT I
     IF T% = 1 THEN
        I1% = 1
        I2% = FLAG%
     ELSE
        I1% = I1% + FLAG%
        I2% = I2% + FLAG%
     END IF
     FOR J = 1 TO N%
         FOR I = I1% + (J - 1) TO I2% + (J - 1) STEP N%
             CH!(J) = (2047 - ARRAY%(I)) / 819.2 + CH!(J)   'CONVERT TO
VOLTAGES
         NEXT I
     NEXT J
```

```
'
'
1000 FOR I = 1 TO N%
        CH!(I) = CH!(I) / TS%                  'PSIG TRANSDUCER
    NEXT I
'
END SUB
```

Appendix B. *Pressure Transducer Calibration Curves*

The calibration curves of the pressure transducers used in this research are presented in the following figures.

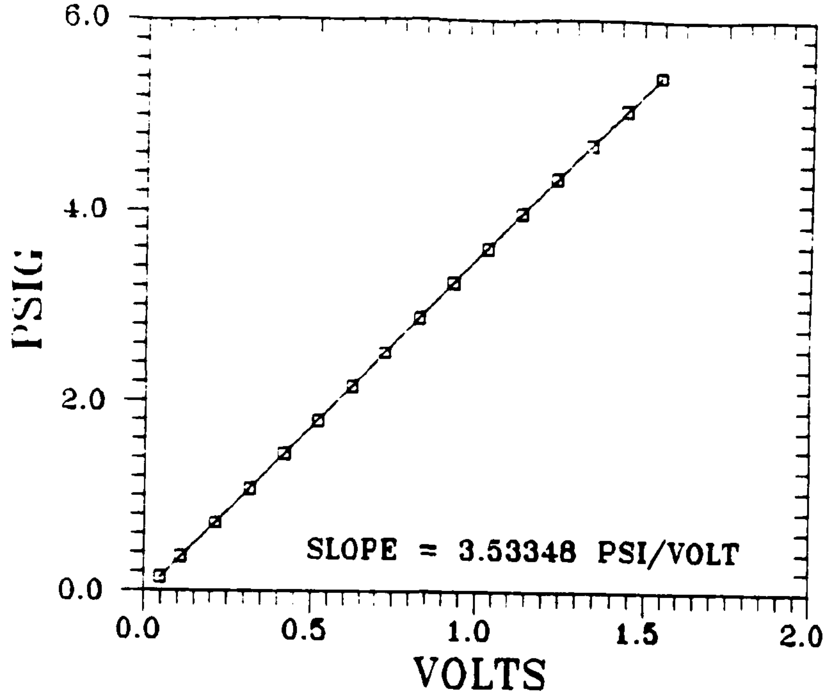

Figure B.1. Calibration Curve for Pressure Transducer 8510B-5 Serial Number: PP81

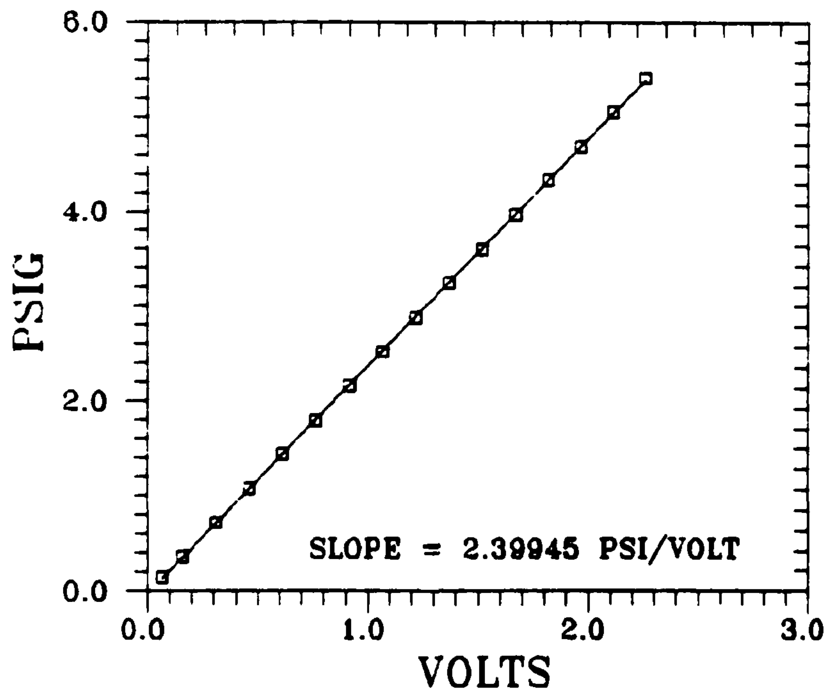

Figure B.2. Calibration Curve for Pressure Transducer 8510B-5 Serial Number: 79HB

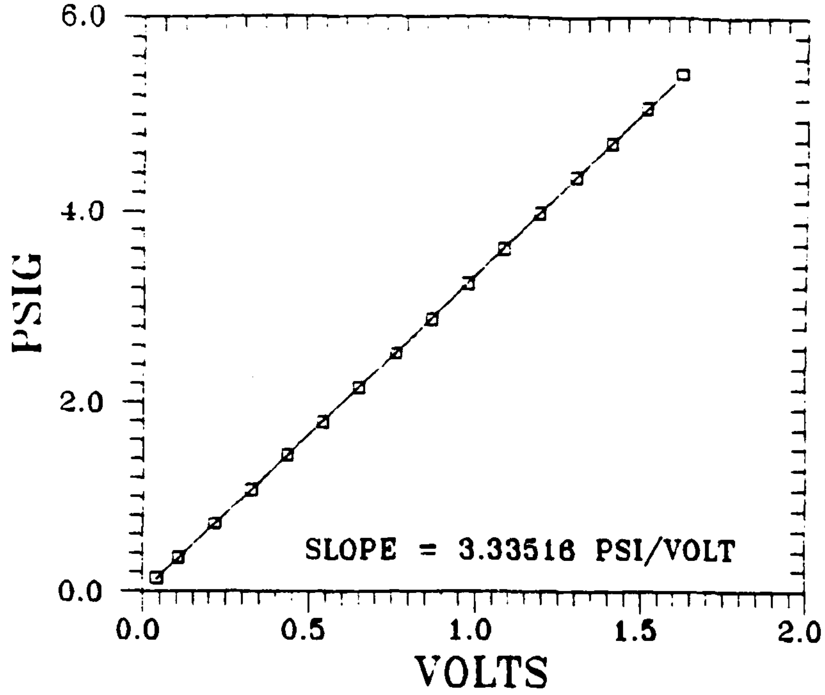

Figure B.3. Calibration Curve for Pressure Transducer 8510B-5 Serial Number: 78HB

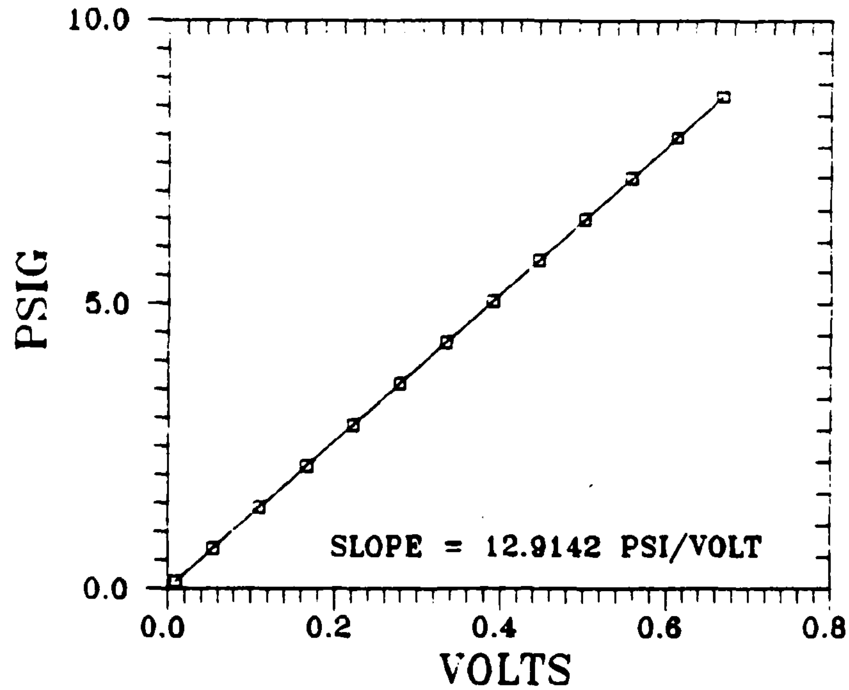

Figure B.4. Calibration Curve for Pressure Transducer 8510B-15 Serial Number: 9BYP

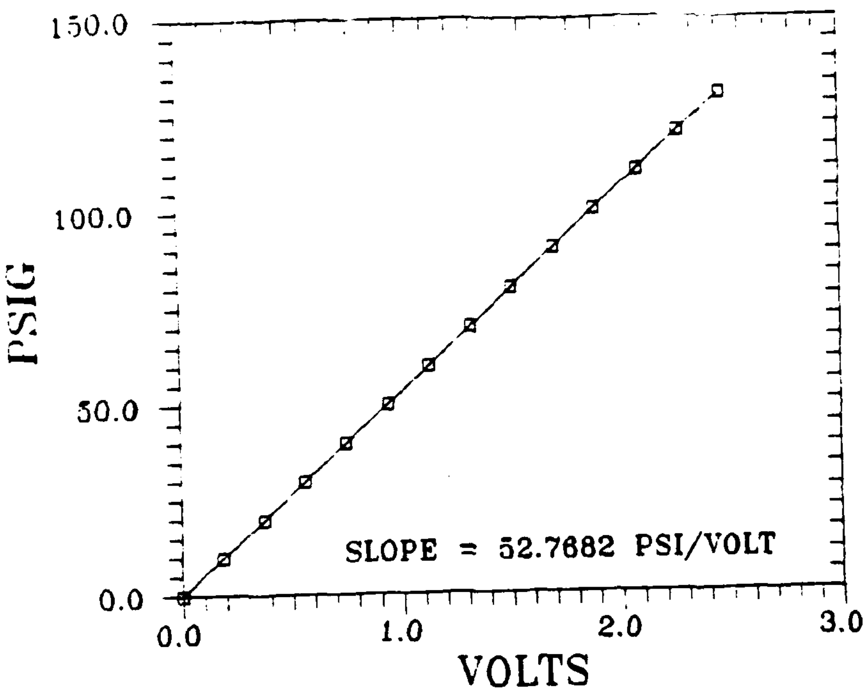

Figure B.5. Calibration Curve for Pressure Transducer 8510B-100 Serial Number: 35DF

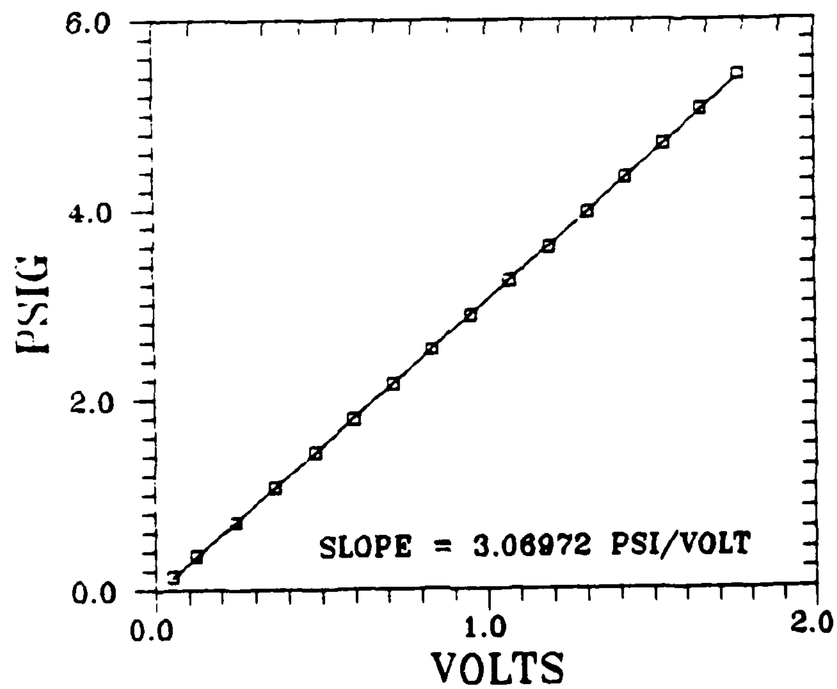

Figure B.6. Calibration Curve for Pressure Transducer 8506B-5 Serial Number: 92BF

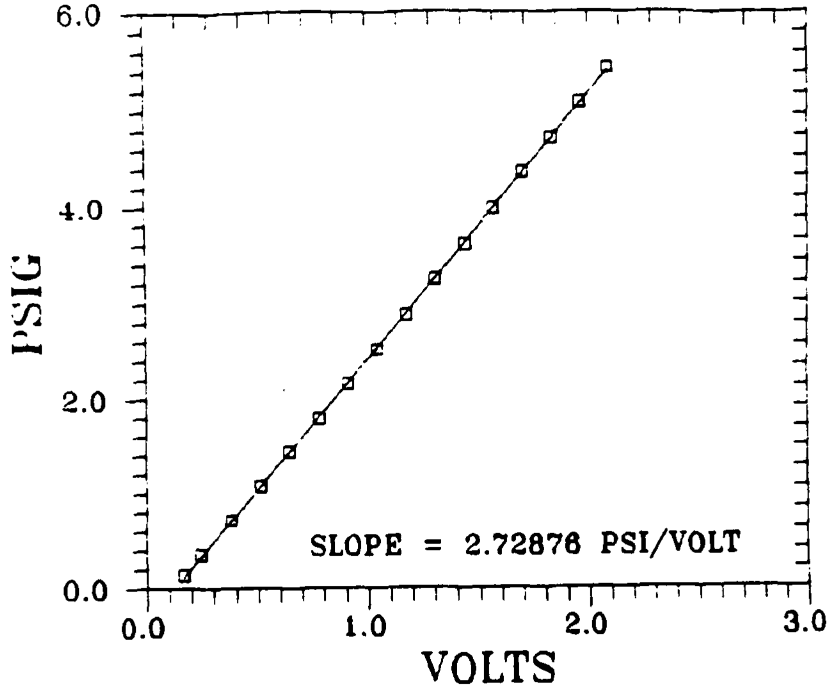

Figure B.7. Calibration Curve for Pressure Transducer 8506B-5 Serial Number: 68BF

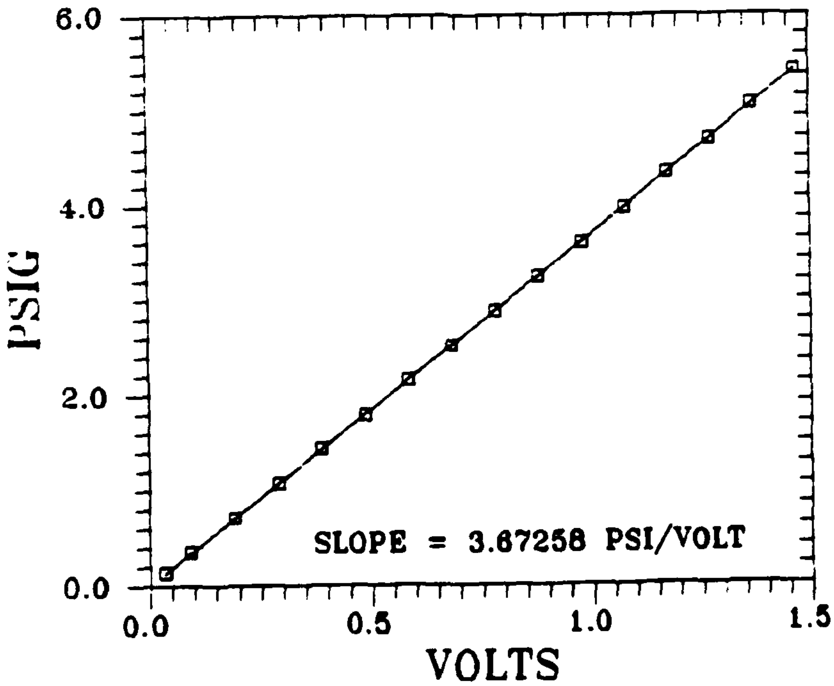

Figure B.8. Calibration Curve for Pressure Transducer 8506B-5 Serial Number: 74BF

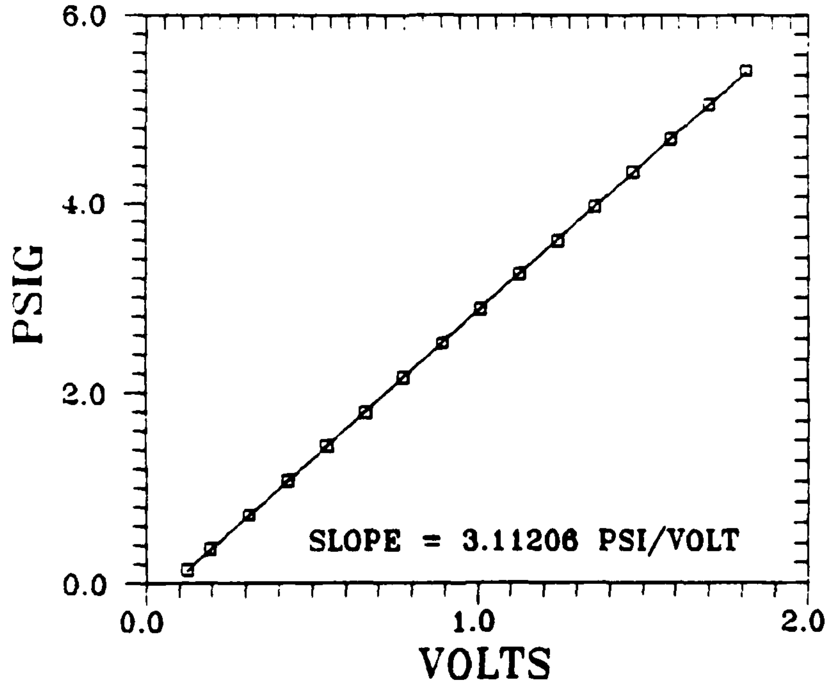

Figure B.9. Calibration Curve for Pressure Transducer 8506B-5 Serial Number: 79BF

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Vita

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Abstract

Chemical lasers require a cavity that establishes and maintains the proper gas dynamic properties during lasing. The design and performance of a flow system capable of supporting the hypersonic flow conditions in a lasing cavity are described. Using cold air as the working medium, the flow control system configuration and nozzle-cavity-supersonic diffuser assembly configuration were developed to establish acceptable flow conditions in the test section. Performance evaluation was based on pressure measurements in the nozzle-cavity-diffuser assembly and schlieren photographs of the flowfield in the cavity.

Flow conditions in the test section were broken up into three different regions: flow in the hypersonic nozzles, flow in the base region and flow in the cavity region.

Flow in the nozzles was analyized using one–dimensional, steady, isentropic flow theory. Test results indicated that the hypersonic nozzles performed to design specifications.

The Korst two–dimensional base–pressure flow model was used to describe the flow in the nozzle exit plane and base region. Experimentally calculated Mach numbers and static pressures corresponded very closely to theoretical values.

Static pressure ports and schlieren photographs were used to describe the flowfield conditions in the cavity region. Pressure measurements indicated that supersonic conditions were reached in the cavity for specific supersonic diffuser throat areas settings, but conditions were short lived. Boundary layer, frictional, and three–dimensional effects were suspected as the main contributors to the flowfield degradation.